United States Department of Energy

Nuclear Criticality Safety Program

Five Year Plan

August 1999

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LIST OF ACRONYMS

ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI/ANS	American National Standards Institute/American Nuclear Society
APT	Accelerator Production of Tritium
AROBCAD	Applicable Ranges of Bounding Curves and Data
BIO	Basis for Interim Operation
BNL	Brookhaven National Laboratory
CAAS	Criticality Accident Alarm System
CERES	Franco-British Critical Experimental Series
CSBEP	Criticality Safety Benchmark Evaluation Project
CSCT	Criticality Safety Coordinating Team
CSEWG	Cross Section Evaluation Working Group
CSIRC	Criticality Safety Information Resource Center
CSSG	Criticality Safety Support Group
DNFSB	Defense Nuclear Facilities Safety Board
DOE	United States Department of Energy
DP	Office of Defense Programs
EH	Office of Environment, Safety and Health
EM	Office of Environmental Management
ENDF	Evaluated Nuclear Data File
FM	Facility Management
FTE	Full-Time Equivalent
ICNC	International Conference on Criticality
ICSBEP	International Criticality Safety Benchmark Evaluation Project
INEEL	Idaho National Engineering and Environmental Laboratory
IPD	Information Preservation and Dissemination
IPPE	Institute of Physics and Power Engineering
LACEF	Los Alamos Critical Experiments Facility
LANL	Los Alamos National Laboratory

LLNL	Lawrence Livermore National Laboratory
MD	Office of Fissile Materials Disposition
MOX	Mixed Oxide Fuel
NCS	Nuclear Criticality Safety
NCSD	Nuclear Criticality Safety Division
NCSET	Nuclear Criticality Safety Engineer Training
NCSP	Nuclear Criticality Safety Program
NCSPMT	Nuclear Criticality Safety Program Management Team
NCTSP	Nuclear Criticality Technology and Safety Project
NE	Office of Nuclear Energy, Science and Technology
NIST	National Institute of Standards and Technology
NRC	United States Nuclear Regulatory Commission
NSNFP	National Spent Nuclear Fuel Program
OECD-NEA	Organization for Economic Cooperation and Development - Nuclear Energy Agency
ORELA	Oak Ridge Electron Linear Accelerator
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Office
PNNL	Pacific Northwest National Laboratory
RFETS	Rocky Flats Environmental Technology site
RSICC	Radiation Safety Information Computational Center
S/U	Sensitivity and Uncertainty
SAR	Safety Analysis Report
SC	Office of Science
SNM	Special Nuclear Material
SRS	Savannah River Site
SRTC	Savannah River Technology Center
TDQ	Training, Development and Qualification
TWRS	Tank Waste Remediation System
ZEUS	Critical Assembly Machine at Los Alamos
ZPR	Zero Power Reactor

US DOE Nuclear Criticality Safety Program Five Year Plan

EXECUTIVE SUMMARY

The objective of nuclear criticality safety is to ensure that fissile material is handled in such a way that it remains subcritical under both normal and credible abnormal conditions to protect workers, the public, and the environment. A robust line criticality safety program requires knowledgeable people and technical resources. It is essential that the infrastructure which provides these two key elements be maintained so the Department of Energy (DOE) can continue to do work safely with fissile materials.

The Department of Energy recognized the need for maintaining criticality safety infrastructure in its implementation plan in response to Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 97-2, *Continuation of Criticality Safety*. This Recommendation, and the earlier Recommendation 93-2, *The Need for Critical Experiment Capability*, stem from DNFSB concerns that due to reductions in the DOE budget, the national support structure for nuclear criticality safety of site operations was declining to the point that the ability to do work safely and effectively with fissile materials was in jeopardy. The DOE addressed the DNFSB concerns by initiating the Nuclear Criticality Safety Program (NCSP). The NCSP is a comprehensive program which will maintain essential nuclear criticality safety infrastructure.

The Assistant Secretary for Defense Programs (DP-1) is responsible for leading the Department's criticality safety activities. The Departmental Representative to the DNFSB (S-3.1) assists DP-1 in resolving funding issues, if necessary. The Responsible Manager is the Deputy Assistant Secretary for Research, Development and Simulation, Office of Defense Programs (DP-10), who oversees the execution of the NCSP. The Nuclear Criticality Safety Program Management Team (NCSPMT) is responsible for the execution of this Plan. This team consists of representatives from the following offices: Defense Programs (DP); Environmental Management (EM); Environment, Safety and Health (EH); Science (SC); Fissile Materials Disposition (MD); and Nuclear Energy, Science and Technology (NE). The NCSPMT, co-chaired by members from DP and EM, advises and assists the Responsible Manager on technical and programmatic issues involving the implementation of crosscutting NCSP activities. The NCSPMT receives technical support from the Criticality Safety Support Group (CSSG). The CSSG is a standing group of recognized criticality safety experts from Department of Energy and contractor communities, and helps resolve technical criticality safety issues.

This Five Year Plan for the DOE NCSP is focused on maintaining fundamental infrastructure that enables retention of DOE capabilities and expertise in nuclear criticality safety necessary to support line criticality safety programs. In the past, weaknesses have developed in the DOE criticality safety program due to funding reductions and the fact that the program was spread among many program and field offices. Such weaknesses can have significant impacts on operations, including operations necessary to resolve safety commitments. As an example, difficulties in implementing criticality safety practices have negatively impacted some activities associated with the DOE response to DNFSB Recommendation 94-1, *Improved Schedule for Remediation*. The focus of the NCSP is to address these weaknesses by providing a stable, cross-organizational infrastructure to implement criticality safety improvements. These include improving the technical knowledge of criticality safety personnel and improving the availability and use of criticality safety information, tools and guidance throughout the DOE complex. Effective implementation of NCSP activities is important to the successful completion of Departmental programs to address safety concerns raised in DNFSB Recommendations 97-1, 94-1, and 95-2.

The NCSP will also be able to respond to changing requirements in the field of criticality safety. The primary means for achieving this goal is to maintain the criticality safety infrastructure within the DOE so that programs in individual areas such as training, critical experiments, benchmarking, data and methods development can be conducted in coordination with each of the other areas of the NCSP. With these improvements, important safety programs such as the stabilization of nuclear materials, deactivation of contaminated facilities, and providing for secure and safe storage of fissile materials can be accomplished in an efficient, and timely manner. One priority DOE mission already benefitting from the work of the NCSP is the the Spent Nuclear Fuel Program at Idaho.

The NCSP includes the following seven technical task areas:

> <u>Critical Experiments</u>: provide experimental data for the validation of the calculation methods used to support criticality safety analyses.
>
> <u>Benchmarking</u>: identify, evaluate and make available benchmarked data to support criticality safety analyses.
>
> <u>Nuclear Data:</u> provide nuclear cross section data required for codes to address the effect of different materials which are being mixed with fissile material in waste conditioning/disposal operations.
>
> <u>Analytical Methods:</u> support and enhance numerical processing codes used in criticality safety analyses.
>
> <u>Applicable Ranges of Bounding Curves and Data:</u> develop method(s) to interpolate and extrapolate from existing data.
>
> <u>Information Preservation and Dissemination:</u> collect, preserve and make readily available criticality safety information.
>
> <u>Training and Qualification:</u> maintain and improve training of criticality safety practitioners and establish federal and contractor qualification standards."

Each of these areas is interdependent on the others and together form a complete criticality safety program. If any of these program tasks is eliminated, the ability of the Department's criticality safety engineers to perform their work will be compromised. The technical task areas will be coordinated under an administrative task, Program Management and Integration.

A summary budget for the NCSP is shown below. Details for each task are given in the respective sections of the Plan.

Program Task or Subtask	Laboratory or Office	FY 2000 & Beyond Budget ($k)
NCSP Management	DP-10/EM-66	170
Critical Experiments	LANL LACEF	3,950
Benchmarking	INEEL, LANL, LLNL, ORNL, Y-12, ANL, SRS	1,500
Nuclear Data	ORNL, LANL, & ANL	2,217
Analytical Methods	ORNL, LANL, & ANL	1,303
Applicable Ranges of Bounding Curves And Data (AROBCAD)	ORNL	700
Information Preservation and Dissemination	LANL, LLNL	110
Training, Development & Qualification	LANL, ANL	250 (1)
	TOTAL:	10,200
(1) Supplemented by ~ $84k from tuition collection		

United States Department of Energy
Nuclear Criticality Safety Program

Five Year Plan

1.0 Introduction

1.1 Background

The objective of criticality safety is to ensure that fissile material is handled in such a way that it remains subcritical under both normal and credible abnormal conditions. Maintenance of an effective criticality safety program requires a comprehensive plan that integrates the knowledge, experience and capabilities of Department of Energy (DOE) resources and personnel from a number of areas including safety, nuclear science, facility operations and process control. To execute this plan, it is essential that the requisite criticality safety program infrastructure be maintained so that program activities such as training, critical experiments, nuclear data measurements, methods development and other technical tasks can be performed.

The Department of Energy recognized the need for maintaining criticality safety infrastructure in its implementation plan in response to Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 97-2, *Continuation of Criticality Safety*[1]. This Recommendation, and the earlier Recommendation 93-2, *The Need for Critical Experiment Capability*[2], stem from DNFSB concerns that due to reductions in the DOE budget, the national support structure for nuclear criticality safety of site operations was declining to the point that the ability to do work safely and effectively with fissile materials was in jeopardy. The DOE addressed the DNFSB concerns by initiating the Nuclear Criticality Safety Program[3] (NCSP). The NCSP is a comprehensive program which will maintain essential nuclear criticality safety infrastructure.

1.2 Plan Benefits

The NCSP is essential for continued safe, efficient operation with fissile materials. Over the years, the strong base of expertise in the area of criticality safety has steadily diminished along with the Department's capability to perform critical experiments. The primary goal of the NCSP is to maintain a satisfactory capability in the field of criticality safety by reversing this trend through training new practitioners, maintaining facilities to conduct critical experiments and nuclear cross section measurements, developing new and improved analytical methods, and increasing the database of validation benchmarks.

The data, methods, benchmarks and critical experiments programs that were developed in support of the weapons production and reactor development missions in prior years are not necessarily directly applicable to the new DOE missions of deactivation and decommissioning, stabilization of residues, and processing wastes. The diverse operations at sites across the DOE complex now involve hundreds of tons of highly enriched uranium and weapons-grade plutonium, nearly 100,000 spent light water reactor fuel assemblies, other defense and DOE reactor fuel, and hundreds of thousands of transportation and storage packages containing fissile material. The technical tasks of the Plan are meant to maintain the infrastructure and support all programs with fissile material operations and to focus the use of this infrastructure on these changing needs.

In the past, weaknesses have developed in the DOE criticality safety program due to funding reductions and the fact that the program was spread among many independent offices[4]. Such weaknesses can have significant impacts on operations, including operations necessary to resolve safety commitments. As an example, difficulties in implementing criticality safety practices have negatively impacted some activities associated with the DOE response to DNFSB Recommendation 94-1, *Improved Schedule for Remediation*[5]. The focus of the NCSP is to address these weaknesses by providing a stable, cross-organizational infrastructure to implement criticality safety improvements. These include improving the technical knowledge of criticality safety personnel and improving the availability and use of criticality safety information and guidance throughout the DOE complex. Effective implementation of NCSP activities is important to the successful completion of Departmental programs to address safety concerns raised in DNFSB Recommendations 97-1, 94-1, and 95-2.

The NCSP will also be able to respond to changing requirements in the field of criticality safety. The primary means for achieving this goal is to maintain the criticality safety infrastructure within the DOE so that programs in individual areas such as training, critical experiments, benchmarking, data and methods development can be conducted in coordination with each of the other areas of the NCSP. With these improvements, important safety programs such as the stabilization of nuclear materials, deactivation of contaminated facilities, and providing for secure and safe storage of fissile materials can be accomplished in an efficient, and timely manner. One example of a priority DOE mission already benefitting from the work of the NCSP is the Spent Nuclear Fuel Program at Idaho.

1.3 Requirements

In addition to the fundamental requirement to maintain criticality safety, there are statutory requirements as defined by Title 10 of United States Code of Federal Regulations and the DOE Orders.[6, 7] Those statutory requirements are drawn directly from national standards[8] that require the competent and responsible application of the necessary knowledge to Departmental work and activities in a safe manner while assuring acceptable risks and efficiency of operations. In particular, Departmental operations and oversight of operations must maintain an administrative and technical infrastructure to competently administer a nuclear criticality safety program. These standards are the basis for the pursuit, development, and optimization of applied knowledge, methods, and applications of techniques to address safety and the evolving needs of the Department.

The Department's mission focus has changed dramatically in the past decade from materials production and processing for use in nuclear weapons and nuclear fuels to materials processing to stabilize fissile materials for storage or disposal. Operations that support the disposition of the Department's fissile materials present new criticality concerns because they involve partially moderated systems where intermediate-energy neutrons are major potential contributors to the state of criticality of the system. In the past, the intermediate-energy portion of the neutron spectrum was of little concern to nuclear reactor and nuclear weapon designers. However, to a criticality safety engineer, faced with analyzing processes related to stabilizing fissile material for storage or disposal, the entire neutron energy spectrum, including the intermediate energy region, must be considered. In addition, these systems contain packaging and storage materials, some of which have received scant previous attention with regard to the measurement and qualification of nuclear cross section data.

In the past, with regard to nuclear criticality concerns, conservatism was employed when uncertainties in calculational methodologies arose. In most cases, this conservatism translated into additional storage or process line space which increased operational costs. Currently, during this time of extreme budget pressure, it makes sense to address the uncertainties in calculational methodologies that lead to the application of unnecessary and costly conservatism. A modest investment in improving nuclear criticality predictive capability could yield large operational cost savings while enhancing criticality safety. Considering the change in Departmental missions coupled with the persistent budget pressure, maintaining a viable nuclear criticality predictive capability is as important today as ever.

Each task within the NCSP contributes to the ability of the DOE to meet these requirements by establishing a coordinated infrastructure necessary to establish and implement a cross-cutting criticality safety program. Individual tasks are also developed to meet current needs of the DOE that are related to its ongoing missions. The relationship of the NCSP tasks to these needs and requirements are detailed in the following sections of this Plan.

1.4 Plan Summary

This Five Year Plan for the DOE NCSP presents the integrated program needed to maintain the infrastructure that will allow the DOE to retain its capabilities and expertise in this area for the next five years. Within the limits of the resources available to the program, and in support of its primary focus, the NCSP will address specific evolving issues in criticality safety. NCSP personnel will solicit information from field sites and DOE programs so that such evolving issues (e.g., remediation of new combinations of materials, impact of cross section uncertainties on operational limits) can be addressed and included in NCSP planning.

The NCSP includes seven technical task areas: Critical Experiments, Benchmarking, Nuclear Data, Analytical Methods, Applicable Ranges of Bounding Curves and Data, Information Preservation and Dissemination, and Training and Qualification. Each of these areas is interdependent on the others and together form a complete criticality safety program. If any of these program tasks is eliminated, the ability of the Department's criticality safety engineers to perform their work will be compromised. The technical task areas will be coordinated under an administrative task, Program Management and Integration.

Each task area will be discussed in the following sections of this Plan, but the contributions of each task to the program areas follows.

Critical Experiments: provide experimental data for the validation of the calculation methods used to support criticality safety analyses. Currently, experiments being planned and conducted at Los Alamos National Laboratory (LANL) will provide data for validation of criticality safety evaluations for the Spent Nuclear Fuel Program at Idaho.

Benchmarking: identify, evaluate and make available benchmarked data to support criticality safety analyses. In order for analytical results to be properly validated, they must be compared to benchmark experiments. Benchmarking is a major international effort led by the United States to compile and disseminate benchmark data to fill important gaps in our data base. Data compiled by this program is being used at every DOE site where criticality safety evaluations are being produced.

Nuclear Data: provide nuclear cross section data required for codes to address the effect of different materials which are being mixed with fissile material in waste conditioning/disposal operations; this involves the following major activities: measure nuclear cross section data at the Oak Ridge Electron Linear Accelerator (ORELA), evaluate it, assemble it into libraries, and update the required numerical processing methods so that the libraries can be used for criticality calculations. Nuclear cross section data is being acquired and processed at Oak Ridge to support calculations for criticality safety evaluations for priority DOE missions.

Analytical Methods: support and enhance numerical processing codes used in criticality safety analyses. Complex neutronics codes (KENO, MCNP, VIM) are being supported and enhanced by the NCSP; these codes are being used by criticality safety practitioners throughout the DOE complex to perform criticality safety evaluations.

Applicable Ranges of Bounding Curves and Data: develop method(s) to interpolate and extrapolate from existing experimental benchmark data. A plan to develop the bounding data and curves methodology has been approved and work began in January 1999. First outputs are expected in the Fall of 1999. This will help criticality safety practitioners validate calculations in areas where experimental benchmark data are unavailable or very limited.

Information Preservation and Dissemination: collect, preserve and make readily available criticality safety information. Data and information that may otherwise have been lost is being preserved and placed on the web; data and other information important to criticality safety is now available on a web site with links to other useful sites.

Training and Qualification: maintain and improve training of criticality safety practitioners and establish federal and contractor qualification standards. Hands-on training at Los Alamos always has been and is still in demand; a new training course at Los Alamos will be piloted this fiscal year; other training materials have been developed and will be made available on the web this fiscal year; qualification standards for federal and contractor employees have been developed and are going through final review and approval for use.

2.0 Program Management and Integration

2.1 Organization

The Department recognizes that a coherent nuclear criticality safety program which performs essential crosscutting activities that are spread throughout the complex and various program offices requires an effective management team with strong technical support. Involvement of all affected Program Offices and communication with the technical community are essential to conduct a coherent and efficient criticality safety program. Only with sound technical support will the program managers be able to prioritize the tasks of the NCSP within the limited budget of the Program.

Figure 1 depicts the NCSP management structure. The Assistant Secretary for Defense Programs (DP-1) is responsible for leading the Department's criticality safety activities. The Departmental Representative to the DNFSB (S-3.1) assists DP-1 in resolving funding issues, if necessary. The Responsible Manager is the Deputy Assistant Secretary for Research, Development and Simulation, Office of Defense Programs (DP-10), who oversees the execution of the NCSP. The Nuclear Criticality Safety Program Management Team (NCSPMT) is responsible for the execution of this Plan. This team consists of representatives from the following offices: Defense Programs (DP); Environmental Management (EM); Environment, Safety and Health (EH); Science (SC); Fissile Materials Disposition (MD); and Nuclear Energy, Science and Technology (NE). The NCSPMT, co-chaired by members from DP and EM, advises and assists the Responsible Manager on technical and programmatic issues involving the implementation of crosscutting activities of the Department's criticality safety program. The NCSPMT receives technical support from the Criticality Safety Support Group (CSSG). The CSSG is a standing group of recognized criticality safety experts from Department of Energy and contractor communities, and helps resolve technical criticality safety issues. Both the NCSPMT and the CSSG were established by charters designating initial members[9].

In order to enhance communications with DOE criticality safety practitioners, an additional group has been formed that regularly discusses problems and conveys results to and from the NCSPMT. The Criticality Safety Coordinating Team (CSCT) is composed of DOE representatives from each of the field offices whose sites conduct activities with fissile materials. The CSCT is the primary source of information for DOE field office concerns, and promulgates guidance and information from the NCSPMT to the field. The CSCT charter is approved by the NCSPMT.

Several paths for communication with the NCSPMT and the CSSG exist: criticality safety practitioners at DOE contractor sites have formed an end-users group to discuss criticality safety matters; the Nuclear Criticality Safety Division of the American Nuclear Society organizes several technical sessions at each national meeting and holds special sessions to discuss the NCSP; the

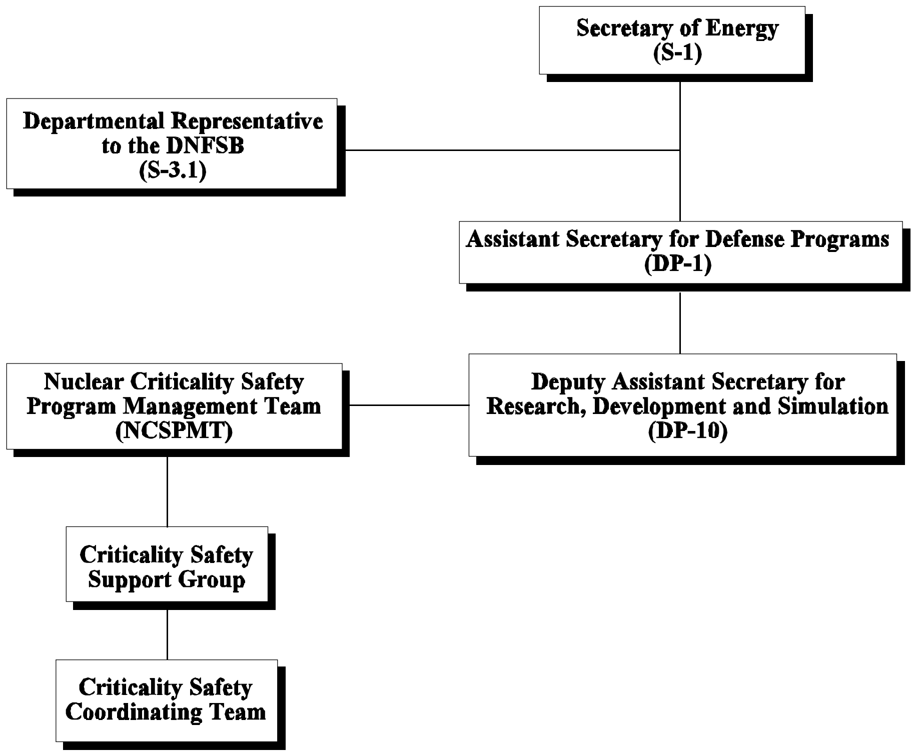

Figure 2-1. Department of Energy Nuclear Criticality Safety Program Organization

Nuclear Criticality Technology and Safety Project (NCTSP) holds an annual meeting with a format that promotes discussion of current criticality safety programs and issues.

In addition to the routine exchange of information among the above-mentioned groups, it is expected that more formal methods will be used to assess the needs of individual sites and to provide program direction based on those assessments. To that end, periodic discussions will be held with DOE field managers to inform them of the NCSP status and solicit feedback to help prioritize tasks within the NCSP. To initiate this series of discussions, a workshop on the NCSP for DOE field managers was conducted August 3-4, 1999..

To provide the same level of interaction with DOE contractor organizations, site visits will be scheduled to discuss the NCSP with line management, nuclear criticality safety (NCS) site representatives and site practitioners. Members of the NCSPMT and CSSG will conduct these visits to encourage a free exchange of information that can be used to help adapt the NCSP to changing needs of the sites.

2.1 Budget Summary

A summary budget for the NCSP is shown in Table 2-1. Details for each task are given in the following sections. This budget projection assumes a flat budget for the next five fiscal years.

The NCSPMT will retain a small amount of program funds to support CSSG activities and respond to unforseen program needs. The projected NCSPMT budget is $170k per year.

Table 2-1. NCSP Funding by Program Task and Subtask

Program Task or Subtask	Laboratory (Point of Contact)	FY 2000 & Beyond Budget ($k)
NCSP Management	DP-10/EM-66	170
Critical Experiments	LANL LACEF (Rick Anderson)	3,950
Benchmarking	INEEL, LANL, LLNL, ORNL, Y-12, ANL, SRS (Blair Briggs)	1,500
Nuclear Data	ORNL, LANL, & ANL (Bob Roussin)	2,217
Analytical Methods	ORNL, LANL, & ANL (Mike Westfall)	1,303
Applicable Ranges of Bounding Curves And Data (AROBCAD)	ORNL (Calvin Hopper)	700
Information Preservation and Dissemination	LANL (Tom McLaughlin) LLNL (Song Huang)	110
Training, Development & Qualification	LANL (Tom McLaughlin) ANL (Jim Morman)	250 (1)
TOTAL		10,200

(1) Supplemented by ~ $84k from tuition collection

3.0 Critical Experiments

3.1 Introduction

Historically, most of the expert criticality safety personnel obtained their experience by participating in experimental programs. These personnel are rapidly disappearing, leaving a need to adequately train and qualify new criticality safety engineers in the field of critical experiments.

The Critical Experiments task of the NCSP maintains a fundamental capability for the DOE to be able to perform critical measurements, and within the limits of is resources, to address specific site needs on a prioritized basis. This task includes sub-tasks to:

1) maintain the capability to perform critical experiments that are required to support DOE programs;

2) in coordination with site safety personnel, and considering the results of other tasks with the NCSP, evaluate the critical experiment needs and critical experiments priorities within the DOE;

3) conduct critical experiments to confirm the evaluated nuclear cross section data used to perform calculations in support of nuclear criticality safety evaluations;

4) transfer this knowledge to the criticality safety engineering community through publications and other activities;

5) provide steady-state and pulsed-radiation capability to operationally test and qualify equipment (criticality alarms, dosimetry, etc).

This task also provides support for the hands-on nuclear criticality safety training programs at the Los Alamos Critical Experiments Facility (LACEF) (see Section 9).

In addition, and beyond the scope of the NCSP, infrastructure maintained by the critical experiments task also supports specific program requirements in the stockpile stewardship program, emergency response and counter terrorism program, and the non-proliferation and arms control program.

3.2 Departmental Requirements

In addition to the general requirements of Section 1.2, the Critical Experiments task of the NCSP is also intended to address the needs of the DOE community to meet specific requirements of the American National Standards Institute/American Nuclear Society (ANSI/ANS) Series 8 Standards. These standards form the core of the requirements contained in DOE Orders 5480.24 and 420.1 related to nuclear criticality safety.

The principal requirement met by the Critical Experiments task is that of ANSI/ANS- 8.1. Section 4.3 of this standard states that the bias in a calculational method be "established by correlating the results of critical experiments." This requires that critical experiment results, applicable to the operation, be available. The conduct of a credible critical experiments program, including the publication of scientific results, is essential to maintain expertise and the capability to properly address the nuclear criticality safety issues associated with the conduct of current DOE programs. The Critical Experiments task is needed to improve the basis of criticality safety methodology, answer criticality questions involving new and previously unevaluated materials and configurations, assist in the development and education of criticality safety engineers and other process personnel, and provide a general purpose and highly capable test bed for equipment and methodology qualification and testing.

By maintaining an operating critical experiments program, DOE is in a position to respond quickly to site specific questions as criticality safety branches into non-traditional areas such as long-term geological waste storage and remediation of legacy materials. Within the limits of its resources, the Critical Experiments task will work to include specific requests for information into its ongoing program.

DOE requirements also include training and qualification of personnel in both the scientific and operational aspects of criticality safety. Criticality safety engineers combine both areas of knowledge to evaluate process operations. Process operations personnel mainly utilize the operational knowledge, but also need to be aware of the technical basis of criticality safety and to be introduced to the importance and types of operational controls for this hazard.

The Critical Experiments task also maintains the capability to perform calibrations of criticality alarms and radiation dosimetry equipment and to benchmark the supporting methodology.

The specific experiments needed to meet the Departmental Requirements for critical experiments data are summarized in LA-UR-99-2083. This updated document summarizes the results of the1998 review of LA-12683, *Forecast of Criticality Experiments and Experimental Programs Needed to Support Nuclear Operations In The United States of America: 1994 - 1999*, originally published in July, 1994. This update was generated in a national consensus process, and the update includes a listing of the proposed experimental programs and an overview of the information pertaining to prioritizing critical experiments. The conclusion of the yearly reevaluation of the experimental program is that the program is strongly determined by the criticality safety needs of the DOE complex. Many of the proposed measurements can be incorporated into current experimental activities without a large reallocation of resources.

Table A-1 of Appendix A contains a short summary of the collected experiments and includes an estimate of ranking and resource requirements. A more complete description of the experiments is contained in Appendix A of LA-UR-99-2083. The ranking estimates of low, medium, or high reflect the current priorities. The resource requirements are estimates of the experimental program funding necessary to complete the experiment or experimental program.

Table A-2 is a consensus ranking of the newly collected critical experiments combined with the current high-priority list. The members of the CSSG met and discussed the current experimental program and merged these new experiments into the existing priority list.

The experiments being performed at LANL provide valuable benchmark data for use by the criticality safety community, and the results are transmitted to the International Criticality Safety Benchmark Evaluation Project (ICSBEP) for independent review and dissemination (see Section 4).

3.3 Program Objectives

The Critical Experiments task is a crucial element in meeting the requirements defined in the previous section. The overall objective of the Critical Experiments task is to serve as the basis for the validation of calculational methodologies. This is especially important since new Departmental activities involve non-fissile materials and special nuclear material in new situations not encountered previously, and often involve nuclear cross section data for which no experimental tests are available. For example, essentially no critical experiments data are available to validate calculations and safety evaluations involving Pu and common waste matrices, Pu or ^{235}U in silicon or silicon/water mixtures, Pu or ^{235}U with iron, ^{233}U with anything other than water, and essentially all types of mixed oxide configurations.

Information provided by the Critical Experiments task is needed to confirm the applicability of the nuclear cross section data for new materials (e.g., silicon and iron), new configurations, and in new neutron energy regimes (i.e., intermediate neutron energy systems). Thus, the Critical Experiments task provides data to validate safety evaluations in areas such as: environmental and nuclear facility remediation; and packaging, storage, transportation, and disposition of waste and weapons material.

The hands-on training that is provided as part of the Critical Experiments task of the NCSP has an impact far beyond that obtained in classroom training and is considered to be a high priority activity. In its Recommendation 97-2, the DNFSB noted the importance of such training and urged the development of an additional, advanced hands-on training course. Both the traditional courses and the new advanced course will be offered under the NCSP. Because training is a foundation upon which many other NCSP activities rely, it benefits all organizations that perform or supervise nuclear materials handling operations. The training courses are given at both the introductory and advanced levels. The former are aimed at process line operators and supervisors, regulators, etc. and the latter are aimed at practicing nuclear criticality safety professionals. All DOE and contractor organizations that require qualification of this type benefit from this program.

The high-priority list given in Table A-2 of Appendix A contains 10 experiments. These experiments support both DOE programmatic requirements and the maintenance of capability, which is a basic part of the DOE criticality safety infrastructure. At current resource levels, only the Priority 1, 2, and 7 activities receive significant attention, although planning and discussion relating to the performance of the other high-priority activities does take place. Performance of these experiments beyond more than a rudimentary level (including aspects that may be conveniently performed under activities 1, 2, or 7) typically depends on obtaining some extra resources specifically for those activities. Appendix A contains an extended description of these ten programs, which are summarized below.

Priority 1: Intermediate-energy reactivity worth and dosimetry experiments using non-fissile matrix materials (ZEUS)

Priority 2: Intermediate- and thermal-energy in specified waste matrices

Priority 3: Measurements of worth of CERES fission-product samples for support of burn-up credit

Priority 4: Single-unit and array experiments for pit storage and transportation, including experiments to simulate dissolution

Priority 5: Experiments to determine effects of special moderators (e.g., beryllium, graphite, D_2O, high-density polyethylene) and absorbers (e.g., chlorine) on fissile materials in homogeneous and heterogeneous systems

Priority 6: Lattice experiments with mixed-oxide (MOX) fuel pins, including replacement measurements for various materials

Priority 7: Criticality (accident) alarm system (CAAS) testing with SHEBA-II and Godiva.

Priority 8: Verification of positive temperature coefficients for dilute systems with nearly pure ^{239}Pu

Priority 9: Extension of National Institute of Standards and Technology (NIST) neutron slowing-down experiments in water to larger spheres of water

Priority 10: Source jerk/pulsed neutron measurements for subcritical systems

3.4 Accomplishments

The LACEF provides critical experiments data for use in validation of calculational methodology in support of DOE programs in the areas of weapons, nuclear emergency response, environmental management and materials disposition. Current LACEF programs are intended to provide data for systems for which data either does not exist (e.g., ^{239}Pu, ^{233}U and expected matrix materials) or is sparse (e.g., ^{235}U) in the composition or energy regions of those systems.

Recent specific accomplishments at the LACEF include the following.

1. Intermediate energy cross section tests for ^{235}U, ^{239}Pu, and ^{233}U

The first ZEUS experiments have been completed using a carbon-^{235}U heterogeneous assembly on the COMET assembly. This program provides data from critical assemblies where the fissions take place at intermediate neutron energies. Subsequent measurements will provide similar data for ^{239}Pu and ^{233}U, and for common matrix materials encountered in the storage, transportation, and disposition of waste and excess weapons materials. Examples of activities requiring this data include materials disposition, such as casting of ^{239}Pu into glass and the storage, transportation, and disposition (e.g., into geologic storage) of those materials; handling and disposition of large scale waste boxes containing ^{235}U-iron (steel) mixtures; handling and disposition of ^{233}U currently stored under thermal (well understood) conditions; and validation of spent fuel burn-up credit.

2. Thermal spectrum tests of common matrix materials

Similar to the intermediate energy experiments described above, the cross section tests for common waste or other matrix materials are in progress. These tests are being performed on the PLANET assembly, using a heterogeneous mixture of ^{235}U, polyethylene, and the matrix material. The first matrix material being tested is silicon (actually, silicon dioxide in the form of glass) with the amount of matrix material and Plexiglas varied to provide different hydrogen to material ratios. When the silicon tests are complete, the experiments will proceed to other matrix materials of immediate interest such as iron and aluminum. Data from these tests, as with item (1) above, are needed by those programs which handle any of the three fissile species in conjunction with the matrix materials tested. This set of experiments, together with those conducted under (1) above, form a complete set of validational data for the three fissile species and the common matrix materials which are expected to be encountered in cleanup and disposition of the DOE complex. This includes spent fuels, excess weapons materials, and current ^{235}U and ^{239}Pu waste streams (e.g., the Hanford waste tanks).

3. Replacement measurements for ^{233}U using the SHEBA assembly

Reactivity worths for ^{233}U were measured for three representative fission-causing spectra. The results compared well with Monte Carlo calculations for the experiments. These results are needed for validation of nuclear materials handling processes involving ^{233}U (including storage, transportation, and disposition) in other than thermal energy spectra.

4. Conduct of nuclear criticality safety training

In collaboration with the LANL criticality safety group, LACEF provides the facilities used in the basic nuclear criticality safety training class for DOE complex personnel. In mid-August 1998, the facility went into a stand-down mode, and the classes did not resume until July 1999. These classes are essential in the training of personnel involved in nuclear operations where criticality is a concern and are included in the qualification program for federal employees involved in nuclear materials handling operations. An advanced version of the traditional course (for subject matter experts) will be piloted in August 1999 and fielded in FY 2000.

5. Process operations support at LANL

LACEF provides critical experiments and other tests of proposed process operations at LANL. Examples are the replacement measurements conducted using the SHEBA assembly and the gadolinium scan tests (in process) conducted in support of the use of gadolinium-loaded plastic in the construction of storage tanks for ^{239}Pu solutions. Construction of the Nuclear Materials Storage Facility at LANL may involve storage under conditions tested under activities (1) and (2) above, e.g., the use of a significant quantity of iron in the storage cans. Planning is underway for the measurement of potential positive temperature coefficients which have been theoretically predicted for dilute plutonium solutions. Critical or near-critical experiments will be conducted using the PLANET assembly machine and sub-critical measurements will be conducted using a tank.

6. Criticality alarm testing

Qualification of the Portsmouth criticality alarms was performed in March 1999, using the Godiva and SHEBA assemblies. These tests are required for Portsmouth by its United States Nuclear Regulatory Commission (NRC) License. Tests of this type are expected to be required in the foreseeable future, as equipment and methodology change. As in the case of Portsmouth, such changes are often driven by manufacturer changes beyond the control of the facility. Similar calibration support is provided to NRC organizations and DOE contractor organizations from across the complex.

7. Dosimetry calibrations

Tests similar to those in activity (6) are performed to qualify neutron dosimetry tools within the DOE complex. Radiation fields of the proper type (neutron spectra and neutron/gamma ratio) were provided to qualify neutron dosimetry equipment for DOE contractor organizations from across the DOE complex. Facilities that do neutron dosimetry are required to qualify the equipment and methodology used for these purposes.

8. Critical mass and delayed neutron properties for ^{237}Np

Replacement measurements using the FLATTOP assembly and activation measurements using the Godiva assembly were made to measure the critical mass and the delayed neutron yields for ^{237}Np. These basic criticality physics parameters are needed to support materials handling processes involving ^{237}Np for anything other than thermal systems.

9. Qualification of Accelerator Production of Tritium (APT) targets

Targets for both the accelerator version and the reactor version were qualified by measuring the relevant parameters using the SHEBA assembly. The SHEBA assembly is a liquid-fueled assembly, and has neutron characteristics similar to those anticipated using the two forms of production devices.

10. Initiation of prompt bursts

This is a collaborative experiment which supports the LANL weapons program.

11. Weapons safety tests

This is an experiment designed to validate calculational methodology used in the evaluation of weapons safety under accident conditions.

3.5 Budget and Schedule

Table 3-1 shows the budget, tasks and associated deliverables for the Criticality Experiments task of the NCSP for fiscal years 2000 through 2002. The total estimated funding estimates for fiscal years 2003 and 2004 are given in Table 3-2.

Table 3-1. Schedule and Budget for Critical Experiments Task of the NCSP

	Deliverables and Budget		
	FY 2000 ($k)	FY2001 ($k)	FY2002 ($k)
Task	3950	3950	3950
1) maintain the capability to perform critical experiments	• maintain authorization basis (finish BIO, begin SAR revision) • begin FM staff hiring • initiate disposition of unneeded SNM (U-235, other) • complete acquisition of Pu-239 needed under task 3 • initiate acquisition of U-233 needed under task 3• initiate acquisition of other materials • perform priority maintenance (facility)	• maintain authorization basis (continue SAR revision) • complete FM staff hiring • requalify assembly personnel (operators) • continue SNM disposition (U-235 solution) • complete U-233 acquisition • complete acquisition of other materials • perform priority maintenance (assemblies)	• maintain authorization basis • continue disposition of SNM (other) • perform priority maintenance (assemblies)
2) evaluate the critical experiment needs and critical experiments priorities	• issue call for input • evaluate/prioritize input • revise experiments list as applicable • issue report	• issue call for input • evaluate/prioritize input • revise experiments list as applicable • issue report	• issue call for input • evaluate/prioritize input • revise experiments list as applicable • issue report

3) conduct critical experiments	• initiate conduct of highest priority experiment (Comet/Zeus) • U-235 intermediate energy) • initiate conduct of next priority experiment - waste matrices, thermal energy (Planet) for high priority waste matrices (Si, Fe, Al) • initiate planning for next priority experiment - alternative materials, positive temperature coefficient (Planet, Flattop, solution tanks, ...)	• complete conduct of highest priority intermediate energy U-235 experiments (Comet/Zeus) • initiate conduct of Pu-239 intermediate energy, waste matrices • complete conduct of next priority experiment - waste matrices, thermal energy (Planet) for high priority waste matrices (SI, Al, Fe) • initiate conduct of second priority waste matrices experiments (Cl, Ca, Mg, packing materials) • initiate conduct of third priority experiments - alternative materials, Pu positive temperature coefficient (Planet, Flattop, solution tanks, ...)	• complete conduct of highest priority Pu-239 experiment (Comet/Zeus) • initiate U-233 intermediate energy, waste matrices • continue conduct of second priority experiment - waste matrices, thermal energy (Planet) • initiate conduct of next priority experiment - alternative materials, Pu positive temperature coefficient (Planet, Flattop, solution tanks, ...) • complete one of the third priority experiments (alternative materials, ...)
4) transfer this knowledge to the criticality safety engineering community	• issue progress reports at least annually • publish nationally, e.g., ANS, NCTSP, ICNC, etc.	• issue progress reports at least annually • publish nationally, e.g., ANS, NCTSP, ICNC, etc.	• issue progress reports at least annually • publish nationally, e.g., ANS, NCTSP, ICNC, etc.
5) provide a test bed and pulsed-radiation capability to operationally test and qualify equipment	• maintain SHEBA, Godiva for operations • characterize Godiva (as needed) • characterize SHEBA (free runs, prompt critical operations) • initiate accident methodology studies • submit approval package - SHEBA prompt critical operations with uranyl fluoride fuel	• maintain SHEBA, Godiva for operations • characterize SHEBA and Godiva • SHEBA prompt critical operations (uranyl fluoride fuel)	• maintain SHEBA, Godiva for operations • characterize SHEBA and Godiva • SHEBA prompt critical operations (uranyl nitrate fuel)

Table 3-2. Estimated Out-Year Funding for the Critical Experiments Task of the NCSP

Year	Budget ($k)
2003	3950

Table 3-2. Estimated Out-Year Funding for the Critical Experiments Task of the NCSP	
Year	Budget ($k)
2004	3950

3.6 Extended Program Opportunities

3.6.1 Critical Experiments

The critical experiments task is focused on maintaining the capability to conduct experiments by actually doing one or two critical experiments per year from the priority experiment list. One extended program opportunity would simply be to increase to a more robust critical experiments program by increasing the level of effort on current experiments and by including several additional experiments from the top priority list. This would help the experiments program meet customer needs in a more timely fashion, and meet a wider range of needs. Funding opportunities that would allow the LACEF to conduct the CERES experiments, the verification of the predicted positive temperature coefficients for dilute plutonium systems, and several varieties of subcritical measurements. In addition, the experiments conducted under the NCSP have been concentrated in the area of process criticality safety applications. The end of underground nuclear weapons testing has brought about an era where certification of the stockpile will rely much more heavily on the predictions of calculational models. The validation of these calculational methodologies will be a much more important activity now. Critical experiments can play a vital role in this validation process.

LACEF personnel have been meeting with a number of stockpile stewardship personnel, and a program review has been held with these personnel. The purpose of these activities is to determine new directions for the LACEF program to specifically support stockpile stewardship program needs. Several short white papers are being developed collaboratively among LACEF and stockpile stewardship personnel. It is anticipated that such activities would be extended to include criticality safety and stockpile stewardship personnel from Lawrence Livermore National Laboratory (LLNL) and Sandia National Laboratories (SNL).

3.6.2 Subcritical Experiments

Since the NCTSP meeting, discussions have been held about the use of subcritical experiments to enhance our understanding of methods of predicting criticality. Such methods could be used to complement the work in the various tasks of the NCSP. In discussions with the Oak Ridge National Laboratory (ORNL), such work could be initiated. An example would be a subtask such as:

> Subcritical Noise Measurements with Uranium foils at LACEF (begin in FY 1999 and end in FY 2000, depending on LACEF schedule)

Current plans at LACEF include critical measurements with various moderator and reflector plates using uranium foils. These measurements will provide benchmark data for testing nuclear data being developed under the NCSP. Performance of subcritical noise analysis measurements using the same facility and configurations would be a wonderful complement to the critical experiments. Inclusion of subcritical noise measurements would provide benchmark data at various degrees of subcriticality. These measurements can be performed in collaboration with ORNL and LACEF staff and can be analyzed by ORNL. This would provide the most complete set of data to examine effects of nuclear cross sections uncertainties on calculations at various degrees of subcriticality.

3.7 Points of Contact

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4.0 Benchmarking

4.1 Introduction

The critical experiments program described in Section 3.0 is supplemented by a broad base of available criticality benchmark data. These measured data represent an important resource for validating and enhancing calculational methods. Until recently, no effort had been made to take full advantage of this resource. In 1992, the DOE initiated the Criticality Safety Benchmark Evaluation Project (CSBEP) at the Idaho National Engineering and Environmental Laboratory (INEEL). The purpose of this project is to identify and evaluate a comprehensive set of critical benchmark data, verify the data to the extent possible, compile it into standardized format, perform calculations of each experiment, formally document the work and make it available for use throughout the complex.

In early 1994, the DOE expanded the CSBEP into the International Criticality Safety Benchmark Evaluation Program (ICSBEP) which was accepted as an official activity of the Organization for Economic Cooperation and Development - Nuclear Energy Agency (OECD-NEA). Also managed through the INEEL, the ICSBEP members include the United States, the United Kingdom, Russia, Japan, France, Hungary, South Korea, Slovenia, and Yugoslavia. This project, led by the United States, established an international forum for the exchange of nuclear criticality benchmark data. The first series of evaluations performed by the ICSBEP was published in May of 1995, as an OECD-NEA handbook entitled, “International Handbook of Evaluated Criticality Safety Benchmark Experiments”. The handbook more than doubled in size in September of 1996 when the first revision of the handbook was published and experienced substantial growth for the second and third revisions in September 1997 and 1998, respectively.

The primary area of focus of the ICSBEP is to: consolidate and preserve the information base that already exists in the United States; identify areas where more data are needed; draw upon the resources of the international criticality safety community to help fill identified needs; and identify discrepancies between calculations and experiments. This program represents a tremendous capability. It provides the United States with the ability to access the global database of experimental benchmarks to validate calculational methods that simulate the neutronic behavior of fissile systems.

The ICSBEP continues to be managed at the INEEL; however, the project involves nationally known criticality safety experts from a number of DOE Laboratories including: LANL, LLNL, Savannah River Technology Center (SRTC), ORNL, the Y-12 Plant, Hanford, Argonne National Laboratory (ANL), and the Rocky Flats Environmental Technology Site (RFETS). This broad cross-section of participants ensures that the needs of each DOE site are being met. In general, participants focus on data that are of importance to their site. Participants are also asked to evaluate data that were generated at their respective sites since they are in the best position to access the data, facilities and experimenters who were directly involved with the generation of the data. The ICSBEP is a labor-intensive task that demands the attention of many more criticality safety experts than exist at any one site. It is essential that the benchmarking effort proceed at a fast pace to ensure that all important relevant data are retrieved and evaluated while original experimenters, most of whom are now retired, are still available to answer questions.

4.2 Departmental Requirements

The necessity to validate calculational methodologies by comparison with experimental data has been recognized and practiced by criticality safety experts for decades. Establishment of a bias in any methodology by correlating benchmark experiment results with results obtained by the methodology being validated is a requirement of ANSI/ANS-8.1-1998, whose adherence is required by DOE Order O 420.1. There are also regulatory drivers for transportation and storage of fissile materials that require similar validation of methodologies that are used to establish safety margins.

Since the beginning of the nuclear industry, DOE and comparable government agencies within other countries have performed thousands of criticality safety related experiments. Many of these experiments can be used as benchmarks for validation of calculational techniques. However, many were performed without a high degree of quality assurance and were not well documented. This broad base of criticality safety benchmark data constitutes an important part of the DOE NCSP infrastructure, but evaluation and comprehensive documentation of these data are required to make the data useful to the general community of criticality safety practitioners.

The ICSBEP is an integral part of the DOE Nuclear Criticality Safety Program infrastructure. It systematically consolidates and preserves the benchmark information base that already exists in the United States and expands it by drawing upon the resources of the international criticality safety community. The ICSBEP maintains an essential interface with the Critical Experiments, Analytical Methods, Nuclear Data, Information Preservation and Dissemination, and Applicable Ranges of Bounding Curves and Data tasks. The "International Handbook of Evaluated Criticality Safety Benchmark Experiments" is also an excellent training tool for new criticality safety engineers.

In addition to the broad base of existing experimental data that is addressed and managed by the ICSBEP, there are specific experimental needs that are identified for the Critical Experiments task of the NCSP. For example, the National Spent Nuclear Fuel Program (NSNFP) at the INEEL has a need to validate criticality safety calculations for systems containing large amounts of SiO_2. This effort is focused on moving highly enriched uranium fuels from interim storage at the INEEL to the geological repository at Yucca Mountain. (These data are also of value to all activities associated with fissile contaminated waste streams involving soil or glass.) Failure to move this fuel out of Idaho within the specified time limits would violate agreements between DOE and the State of Idaho and could result in fines and the interruption of naval fuel shipments into Idaho. Because few appropriate benchmarks exist, experiments funded by the NSNFP are being performed at the Institute of Physics and Power Engineering (IPPE) in Obninsk, Russia that will provide at least part of the necessary data. Complementary experiments are being conducted at LACEF. Documentation of these experiments will be submitted to the ICSBEP for review, evaluation, and publication.

4.3 Program Objectives

4.3.1 ICSBEP Support to the DOE NCSP Infrastructure

Large amounts of critical experiments data exist within the United States that have not been evaluated and documented. ORNL and the Y-12 Plant have identified approximately 30 series of experiments representing over 200 critical configurations that are frequently used for validations at their facilities, but have not yet been scheduled for evaluation by the ICSBEP. Engineers at Rocky Flats, Savannah River and the INEEL have also identified several other series of experiments that are used at their facilities that have not yet been evaluated. They also use several from the ORNL list of needed evaluations. LLNL has identified several experimental series that are required at their facilities, including several classified experimental series that could be declassified and evaluated. The ICSBEP systematically evaluates and documents these data according to the selection and prioritization criteria outlined in Section 4.3.2. In addition, the NCSPMT has directed that all critical experiments being conducted or planned at the LACEF should be designed to consensus benchmark specifications and evaluated for inclusion in the ICSBEP handbook.

The DOE must also continue its review of foreign data commensurate with its commitment as part of the ICSBEP process. Continuation of this work at an appropriate level is important because many of these evaluations are very useful in supporting the DOE's mission needs. Some of the data obtained from outside the United States, which is summarized in Appendix B, illustrates how the ICSBEP draws upon the international criticality safety data base to help fill DOE needs.

All non-United States data were obtained at little or no cost to DOE. All have significant value and some can no longer be generated in the United States without major expense. Some of the data given above have helped fill United States data needs that are classified as "high priority" (e.g., dilute plutonium solution data). These data would cost DOE several million dollars to produce in the United States.

There are two additional types of criticality safety data that are equally important, but have only received limited consideration by the ICSBEP. These two areas are (1) criticality alarm and shielding experiments and (2) subcritical experiments. As efforts to evaluate and document critical experiment data begin to decline, the ICSBEP will focus more attention to these areas. It is projected that a decline in critical experiment benchmarking activities can begin during FY 2002 and will reach a "status quo" level near FY 2003. However, by keeping funding for the benchmarking program task at a constant level, work can begin on the other two focus areas.

4.3.2 Experiment Evaluation Selection Criteria and Prioritization

Most of the major DOE Laboratories that deal with fissile material, outside of reactors, have representation on the ICSBEP. Essentially all ICSBEP Working Group members are experienced criticality practitioners, criticality safety experimentalists, or code/data experts. Most are currently on or provide direct support to the criticality safety staff at their respective sites and are very familiar with the validation needs at these sites. Data are selected for evaluation, by these individuals, in consultation with the Chairman of the ICSBEP Working Group according to the following criteria.

1. Unless prior agreement exists to do otherwise, those experimental data that were generated at a particular facility are the responsibility of the evaluator at that facility. In most cases these experiments were performed in support of operations at that facility and are naturally needed by the local criticality safety staff. Those data that are needed most at the generating facility are evaluated first. In most, if not all cases, these data are of use to multiple facilities.

2. Evaluators who are responsible for a particular facility that requires certain experimental data that cannot be immediately evaluated by an evaluator at the point of origin evaluates the required data themselves.

3. Facilities are periodically surveyed to identify specific needs.

4. Beginning in FY 1999, specific benchmark evaluation requests can be submitted through the ICSBEP Internet site (http://icsbep.inel.gov/icsbep). This site can also be accessed through the DOE Nuclear Criticality Safety Program Internet site. Requests that cannot immediately be addressed by the ICSBEP will be discussed with the Criticality Safety Support Group to gain a consensus of the relative importance of the work in progress.

Most evaluated benchmarks are used at multiple DOE sites. For example all plutonium data are of particular importance at LANL, RFETS, LLNL, Hanford, Pacific Northwest National Laboratory (PNNL), and SRTC; however, these data are also used at the INEEL to demonstrate the safety of plutonium bearing waste streams under their responsibility, including licensing of the TRUPACT-II. Low concentrated plutonium solution data were recently listed among the top United States data needs. Once again, these data are not only important to support plutonium operations, but are also essential to validate criticality safety calculations for plutonium bearing waste streams. These data were not available in the United States and would have cost several million dollars over several years to produce. However, these data were obtained from France for only an insignificant cost to review and publish the data.

Low enriched uranium data are valuable to operations at ORNL and at the Oak Ridge Y-12 Plant. Low enriched uranium data from ORNL and PNNL are also used at the INEEL where numerous commercial light water reactor assemblies are or have been used in various DOE programs. Safety analysis calculations supporting INEEL operations involving the TMI-II core debris are validated using many of these same low enriched data.

4.3.3 ICSBEP Support to Specific Programmatic Needs

The ICSBEP will continue to identify data within the international criticality safety community that will help fulfill specific United States needs and will seek ways to encourage contribution or procurement of the needed data. For example, the ICSBEP is supporting the NSNFP at the INEEL in its effort to obtain criticality safety data that can be used to validate calculations of fissile bearing waste streams containing large amounts of SiO_2. The ICSBEP will evaluate and provide independent review of these data as soon as they become available. Working Group review of these data is planned for the spring of 2000 with publication of the data scheduled for September of 2000. If inadequacies are identified in the silicon data, this information will be forwarded to those responsible for the Nuclear Data task.

4.4 Accomplishments

The efforts of the ICSBEP have eliminated much of the redundant and inconsistent efforts of research and model description that took place throughout the DOE complex. For example in 1995, the Savannah River Site (SRS) reported over a $1 Million dollar savings in validation costs at their site alone because of access to the “International Handbook of Evaluated Criticality Safety Benchmark Experiments”. SRS Facilities that were directly impacted by the readily available data in the handbook include H-Canyon, F-Canyon, HB-Line, FB-Line, 235-F, and the Receiving Basin for Off-Site Fuels Facility. Similar validation efforts are made at all DOE non-reactor nuclear facilities and are applicable to all activities involving fissile material.

Over 150 scientists from around the world have combined their efforts to document the work of the ICSBEP as the “International Handbook of Evaluated Criticality Safety Benchmark Experiments”. The 1999 version of the handbook will span seven volumes and contain approximately 268 evaluations with benchmark specifications for nearly 2250 critical configurations. As a result of these efforts, a large portion of the tedious and redundant research and processing of critical experiment data has been eliminated. The necessary step in criticality safety analyses of validating computer codes with benchmark critical data is greatly streamlined, and valuable criticality safety experimental data is preserved. The work of the ICSBEP has highlighted gaps in data, has retrieved lost data, and has helped to identify limiting assumptions in cross section processing codes. The Handbook is currently being used in 35 different countries, with nearly 400 copies already distributed. Appendix B contains a detailed listing of the distribution of the Handbook.

During 1998 ICSBEP participants at the INEEL and the IPPE began the large task of recalculating every configuration in the "International Handbook of Evaluated Criticality Safety Benchmark Experiments" and collecting the spectral characteristics of each experiment. These data represent a significant enhancement to the Handbook and will enable criticality safety practitioners to more clearly understand the range of applicability for each configuration in the Handbook.

Recent contributions from ANL and the IPPE have identified large (>10% in some cases) discrepancies for certain kinds of systems containing large amounts of iron, chromium, nickel, stainless steel, or zirconium. ICSBEP personnel and individuals responsible for analytical methods at ORNL were able to identify both limiting assumptions in cross section processing codes and inadequacies in nuclear cross section data.

As another example, the first contribution to the ICSBEP from Slovenia included data for arrays of 20% enriched uranium TRIGA reactor fuel elements. These data are applicable to transportation and storage of TRIGA reactor fuels at the INEEL. This was a significant contribution because very little data exist for this type of fuel.

4.5 Budget and Schedule

Table 4-1 summarizes the schedule of activities for years FY 2000 through FY 2002 and the associated minimum budget requirements.

Similar tasks will continue during the years 2003 and 2004. However, as data from existing critical experiments are exhausted, benchmarking efforts in this area, at least in the United States, will decline to a level that will enable the evaluation, review, and publication of only new experiments. (Note: If the program at LACEF expands significantly during the out years, the decline in the benchmarking effort could be delayed.) At the same time, the focus of the ICSBEP will turn to the identification, evaluation, and documentation of (1) criticality alarm and shielding experiments and (2) subcritical experiments. The total estimated funding requirements for the years FY 2003 and FY 2004 are given in Table 4-2.

Table 4-1. Schedule and Budget for the Benchmarking Task of the NCSP			
Tasks by Laboratory	FY 2000 ($k)	FY 2001 ($k)	FY 2002 ($k)
INEEL: Provide technical project management support for the International Criticality Safety Benchmark Evaluation Project which is managed by DOE Defense Programs. Provide or coordinate independent review efforts, graphic arts support, technical editing, and publication of the International Handbook of Evaluated Criticality Safety Benchmark Experiments. Participate in the ICSBEP as follows: evaluate and, to the extent possible, verify criticality safety benchmark experiment data, compile the data into a standard format that will provide an accurate basis document for future validation efforts, and perform calculations using the data with standard criticality safety neutronics codes. INEEL will focus primarily on high, intermediate, and low enriched uranium systems and on plutonium solution systems. Where possible, the INEEL will also provide for the documentation of undocumented experimental data.	600	570	420 +50*
LANL: Participate in the ICSBEP with primary focus on high enriched uranium, plutonium, ^{233}U, and mixed plutonium - uranium metal systems.	280	280	180 +100*
SRS: Participate in the ICSBEP with primary focus on high enriched uranium and plutonium metal and solution systems.	195	200	195
ORNL & Y-12: Participate in the ICSBEP with primary focus on high, intermediate, and low enriched uranium metal, compound and solution systems, and on ^{233}U solution systems.	195	200	185 +150*
ANL: Participate in the ICSBEP with primary focus on Zero Power Reactor (ZPR) benchmark data that are relevant to non-reactor criticality safety issues.	180	200	170
RUSSIAN FEDERATION: Participate in the ICSBEP with primary focus on non-reactor criticality safety data that are available within the Russian Federation. Provide spectral data for all evaluations.	50	50	50
TOTAL:	1,500	1,500	1,500
*Specifically allocated for criticality alarm and shielding benchmark data and subcritical benchmark data.			

Table 4-2. Estimated Out-Year Funding for the Benchmarking Task of the NCSP	
Year	Budget ($k)
2003	1500
2004	1500

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5.0 Nuclear Data

5.1 Introduction

Accurate differential nuclear cross section data and their covariances are at the foundation of nuclear criticality predictability. In order for nuclear cross section data to be utilized, it has to be measured, evaluated, put into standard format, tested, released as part of the Evaluated Nuclear Data File (ENDF) library, and then processed into specific formats for subsequent use by the analytical methods. It is important to point out that both the evaluation and the processing activities mentioned here entail significant nuclear-methods development and application efforts that must incorporate fundamental but complex nuclear reaction formalisms, nuclear models, and associated approximations before the measured nuclear cross section data can be used by criticality analytical methods. This is important to note in order to gain a proper perspective for the effort requirements necessarily associated with the Nuclear Data task. As these methods develop (see Section 6), additional data such as covariance matrices are needed. As DOE missions change, new cross section data is often needed for material and energy regions that were not important for past work. Encompassing all of these nuclear data requirements, the Nuclear Data task of the NCSP is divided into three subtasks.

Subtask 1: ORNL – measurement, evaluation, testing, evaluation and processing method development, covariance development, and Cross Section Evaluation Working Group (CSEWG) and international interactions.

Subtask 2: LANL – evaluation, testing, processing method development, covariance development and CSEWG and international interactions.

Subtask 3: ANL – testing, processing method development, covariance development and CSEWG and international interactions.

In the past, analytical methods for criticality prediction used simple geometric and nuclear models of the system. The situation has changed dramatically with the advent of very fast computers and the refinement of the analytical methods. In most of the cases the uncertainty in the results of calculations can be traced to the data rather than to the physical model. Therefore, the uncertainties in the calculations can be reduced if accurate data are used in analyses.

The CSEWG has developed the United States ENDF nuclear data library, with emphasis on the fast, thermal, and fusion reactor communities. Nuclear data needs of the criticality safety community were not given much attention in past versions of ENDF. Now, participants in the Analytical Methods, Benchmark, Nuclear Data, and Applicable Ranges of Bounding Curves and Data (AROBCAD) tasks of the NCSP are actively involved in CSEWG to assure that ENDF will evolve into a reference nuclear data library well suited for criticality safety applications. In addition, one member of the CSSG is a member of CSEWG, and will continue to provide liaison to ensure that the DOE criticality safety nuclear data needs are addressed.

The nuclear data programs at ORNL, LANL, and ANL provided the vast majority of evaluations for ENDF/B-VI, which is the most recent and complete cross section compilation (1990). All three laboratories are participating in the Nuclear Data task. ORNL plays a major role in nuclear data measurement and evaluation. The measurements are performed at the ORELA. ORELA is ideally suited for providing data for criticality safety applications since data can be measured with high resolution over the energy regions important for criticality safety applications. At ORNL, there also exists expertise in data measurements and data evaluation in the resolved and unresolved resonance region. The author of the tool for data evaluation, the SAMMY code, is at ORNL. With SAMMY data, evaluations are made with full uncertainty files (covariance and sensitivity parameters) which are essential for meaningful assessments of the uncertainty in calculated parameters for criticality safety applications. These uncertainties directly impact the calculated margin of sub-criticality. As will be explained in subsequent sections, these types of data are also needed for the AROBCAD task. Resolved resonance covariance data for ^{27}Al, ^{233}U, and ^{235}U will be provided for use by AROBCAD in FY 2000.

Integral benchmark experiments performed at experimental facilities such as the LACEF at LANL serve to test the adequacy of the evaluated data prior to their use in criticality safety calculations.

ANL has played an important role in the area of nuclear data, with significant contributions in the development and application of a wide range of nuclear reaction formalisms in connection with the processing methods in nuclear data. A particularly major contribution is the pole representation of resonance parameters in momentum space, which has been implemented at ORNL in connection with AMPX with support from the ANL and funding from the NRC. Further work in processing methods at ANL continues with incorporation of the of the Single Level Breit Wigner and Multi Level Breit Wigner formalisms in the pole representation and a deterministic treatment for unresolved resonances for VIM. Other areas of contribution at ANL include validation of cross sections and other aspects of nuclear data. ANL will also evaluate a series of covariance files for the ENDF/B-V library currently used by the AROBCAD development group. As budgets permit, ANL, LANL and ORNL will focus on the validation of data evaluations and uncertainty data as confirmed through sensitivity and uncertainty evaluations in concert with the international benchmarking effort. The NCS user community will be alerted to any nuclear data having potential adverse impacts on systems identified through Subtask 3 of the AROBCAD task or other relevant sources of information.

Since 1994, criticality safety practitioners have been surveyed periodically to help identify nuclides which they think have deficiencies and which are relevant to Department operations. Some 60 isotopes or elements with nuclear data deficiencies have been identified in this way. Because of the condition of these evaluated data, many will require new measurements at the ORELA, followed by an evaluation or new evaluation of the ENDF/B-VI file. The goal is to assure that the intermediate energy region is represented well by a resonance parameter fit with SAMMY, including covariance data. Where appropriate, evaluations will be upgraded in the higher energy region at LANL to assure a complete evaluation to 20 MeV (required by ENDF/B).

5.2 Departmental Requirements

As noted in Section 1, the DOE requires compliance appropriate with DOE Orders, Standards and nuclear safety rules. Programmatic drivers include commitments to the DNFSB and environmental, safety and health requirements of DOE. The NCSP is an integrated system set in place to meet these requirements. The NCSP requires a minimum infrastructure to be in place and properly maintained so that it can respond efficiently and effectively to develop specific products to meet customer needs.

The vast majority of the effort in the Nuclear Data task is devoted to the NCSP infrastructure. At ORNL, this includes: having the ORELA facility available for use as part of the NCSP; maintaining a staff of experienced experimentalists, electronics and crafts technicians, and evaluators; maintaining evaluation codes for cross-section processing and benchmark analysis; providing for project management; and participation in CSEWG, the NCTSP, the ANS Nuclear Criticality Safety Division (NCSD) and criticality Standards work. Additional expenditures are required to fabricate samples and pay the cost for operating ORELA during the actual measurements. At LANL the infrastructure deals with maintaining evaluation codes, cross-section processing, and participation in CSEWG, NCTSP, and the ANS NCSD. At ANL, the infrastructure deals with cross-section processing and participation in CSEWG, NCTSP, and the ANS NCSD.

Nuclear criticality safety in DOE fissile material operations, storage, transportation, and waste management relies on accurate nuclear cross section data and analytic methods. Examples of processes involving materials that criticality safety specialists have so far identified to the Nuclear Data task include:

- lithium, sodium, potassium carbonates used in heat treating raw fissile material metals

- freon used in heat transfer systems such as freezer-sublimer equipment in UF_6 enrichment cascades, and also used in thermal shock processes for breaking bonds between materials

- organic/aqueous chemical recovery processes

- process residues/deposits of fissile materials in silicates, chlorides, nitrates, phosphates, carbonates, etc.

- elements of equipment construction materials such as stainless steels, specialized materials (e. g., inconels, hastelloys, monels, etc.)

- hydrated/unhydrated NaCl influences on waste storage configurations

- fresh/spent fuel shipping container analyses.

5.3 Program Objectives

The objective of the Nuclear Data task is to provide accurate nuclear cross section data and their uncertainties in forms useable for criticality safety analyses. The emphasis is on improving nuclear data in the energy regions important for criticality safety applications, and providing it where none exists. The intermediate energy region is the initial focus of this task because that region was not emphasized in earlier versions of ENDF that concentrated on thermal, fast, and fusion reactors. Where new measurements are required they will be performed at ORELA. Evaluations will be done to fit the measured data in the resolved and unresolved resonance region and to produce resonance parameters and their uncertainties. Evaluated data will be placed in ENDF format, tests will be performed to check the data, processed libraries will be produced and calculations of criticality benchmarks will be performed. Satisfactory evaluations will be submitted to CSEWG for inclusion in the ENDF.

Performers of this task will maintain close interaction with the Analytical Methods, Benchmarking, AROBCAD, and Critical Experiments tasks of the NCSP so that an integrated system can be achieved.

5.4 Accomplishments

A number of accomplishments can be cited. A measurement program has been established at ORELA and measurements have been performed on a number of nuclides. The effective use of the SAMMY evaluation code to provide resonance parameter fits and their uncertainties has been demonstrated and its extension to the unresolved region is under way. Collaboration between LANL and ORNL on joint evaluations has been demonstrated. Unresolved resonance processing with the LANL NJOY code and the inclusion of unresolved resonance treatment in the MCNP Monte Carlo code at LANL has been demonstrated.

Based on DOE needs solicited from criticality safety specialists and guidance derived from presentations to DOE management over the last four years, current ongoing projects include: measurements on ^{27}Al capture, ^{233}U transmission and capture, and Cl transmission and capture; evaluation of ^{27}Al, ^{16}O and ^{235}U unresolved resonance regions; review of the status of fission product evaluations; and development of SAMMY evaluation techniques for unresolved and resolved resonance regions and associated covariance matrices. The Al data will contribute to the DOE-EM operations involving aluminum-clad fuel elements and aluminum matrix materials; the ^{233}U data will enable more efficient remediation of sites containing ^{233}U-bearing waste.

5.5 Budget And Schedule

The FY 2000, FY 2001, and FY 2002 budgets are shown in Table 5-1. Inherent is the assumption that DOE's Office of Science (SC) continues to provide *in kind* support for ORELA operations valued at approximately $675k/year (in FY 1997 dollars).

Table 5-1. Schedule and Budget for Nuclear Data Task of the NCSP			
	Deliverables and Budget		
Task by Laboratory	FY 2000 ($k)	FY2001 ($k)	FY2002 ($k)
ORNL	1,776	1,826	1,826
1) Perform differential measurements of neutron cross sections in the energy range of importance to the NCSP using the ORELA at ORNL. Activities include sample and detector preparation.*	1) Potassium (02/2000) and fluorine (05/2000) are scheduled for FY 2000, but identified priority measurements may be substituted, resources permit.	1) Measurements on high priority isotopes related to DOE projects (09/2001)	1) Measurements on high priority isotopes related to DOE projects (09/2002)
2) Perform evaluations of neutron cross-sections for materials of importance to the NCSP using existing and newly measured differential cross-section data. Includes code development on the SAMMY Bayes' R-matrix Fitting Code.	1) Activities include evaluations of the ^{233}U unresolved resonance regions (12/1999), and the Cl resolved resonance region (03/2000); development of resolved resonance covariance data for Al, ^{233}U, ^{235}U, and Cl (03/2000).	1) Activities include evaluations for K and F resolved resonance region (03/2001); development of resolved resonance covariance data for K and F. (09/2001)	1) Activities include evaluations based on FY 2001 measurements. (continuing)
3) Collaborate in upgrading CSEWG benchmarks to reflect the needs of the NCSP, perform benchmark calculations of criticality benchmarks with the VITAMIN-B6 multi-group cross-section library, generate sensitivity profiles for criticality benchmarks to help guide new measurements and evaluations, and participate in the integration of the activities of CSEWG and the international criticality safety community.	1) Test the AMPX capability for the unresolved resonance region. (09/2000)	1) Develop unresolved resonance region covariance formats. (03/2001) 2) Test the AMPX capability for covariance processing. (09/2001)	1) Other activities required by programmatic needs. (continuing)
LANL	267	267	267
1) Collaborate with ORNL to provide complete evaluations concentrating on the fast energy region.	1) Complete fast energy evaluations for ^{235}U (12/1999) and ^{233}U (02/2000).	1) Complete fast energy evaluations for K (09/2001) and F (09/2001).	1) Complete high energy evaluations as needed. (continuing)
2) Processing code development.	Begin development of NJOY capability to process resolved resonance region covariance data.	Finish development of NJOY capability to process resolved resonance region covariance data. (09/2001)	Other activities required by programmatic needs. (continuing)

ANL	174	124	124
1) Collaborate in upgrading CSEWG benchmarks to reflect the needs of the NCSP.	(continuing)	(continuing)	(continuing)
2) Participate in the integration of the activities of CSEWG and the international criticality safety community.	(continuing)	(continuing)	(continuing)
3) Processing code development for ANL, support to ORNL and other special activities.	1) With ORNL and LANL, help assess covariance data and provide appropriate data to AROBCAD task. (09/2000)	1) Develop unified resonance formalism.	1) Develop improved unresolved resonance probability table method.
TOTAL:	2,217	2,217	2,217
* (NOTE: This activity depends on the DOE/ES commitment to the NCSPMT to maintain ORELA in operating condition and to provide technical assistance of up to 1 PY.)			

The total estimated funding for fiscal years 2003 and 2004 are given in Table 5-2.

Table 5-2. Estimated Out-Year Funding	
Year	Budget ($k)
2003	2,217
2004	2,217

5.6 Points of Contact

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6.0 Analytical Methods

6.1 Introduction

The Analytical Methods task of the NCSP is central to an efficient criticality safety program. The methods are applied in the evaluation of fissile systems to establish safe margins of subcriticality. Furthermore, the analytical methods are used to establish controlled parameters through the demonstration of the sensitivity of the fissile system multiplication factor to the reactivity effect of the parameter variation. Design specifications on controlled parameters are incorporated into safety analysis reports, and control limits from criticality safety assessments are incorporated into facility operating procedures. The KENO/SCALE and MCNP software packages are widely used for these purposes. Thus the current and ongoing development and application of analytical methods is an integral part of the DOE NCS infrastructure.

The work under the Analytical Methods task of the NCSP breaks down into four subtasks:

Subtask 1 – Capability maintenance, training and user assistance and needed improvements are performed on the KENO/SCALE software by ORNL. Additionally, a limited amount of administrative and technical support is provided to the NCSP by ORNL staff.

Subtask 2 – Capability maintenance, training and user assistance and needed improvements are performed on the MCNP code and related software by LANL, with associated management support.

Subtask 3 – Capability maintenance, training and user assistance and needed improvements are performed on the VIM code and related software by ANL, with associated management support.

Subtask 4 – The Radiation Safety Information Computational Center (RSICC) at ORNL performs the important function of collecting, packaging, and disseminating the software (codes and cross-section libraries) to the criticality safety community.

Criticality safety is a DOE infrastructure activity that ensures safe fissile material operations throughout the DOE complex. The alternative to the conduct of a good criticality safety program is to restrict fissile material quantities to overly-conservative mass or concentration limits which lead to gross inefficiencies in operations involving significant quantities of fissile material. Since prevention of criticality accidents by maintaining safe margins of subcriticality is a mandatory requirement for fissile material operations in the United States, maintenance of a quality program that includes the proper analytical methods and data is a necessity.

The purpose of this task is to provide the DOE complex with state-of-the-art analytical methods qualified for the evaluation of DOE fissile system applications. Maintenance of an efficient criticality safety infrastructure dictates that sophisticated methods be qualified for the analysis of large quantities of fissile material configured in complex geometries. Analysis of complex geometries generally requires the application of the Monte Carlo method. Overall qualification of the analyses requires technology from the Critical Experiments, Nuclear Data, Benchmarking and

AROBCAD tasks of the NCSP. Additionally, the methods and data should be operational on modern computer platforms and available for distribution to the user community. Also, criticality safety specialists must be trained and assisted in the correct use of the methods and data. Thus, infrastructure maintenance activities include the technologies required to qualify the methods, production software compatibility with current computer platforms, software packaging and distribution to the user community, and training and user assistance. In this regard, the NCSP infrastructure maintenance requires the functions performed in the Analytical Methods task, supplemented by the technology from the four additional NCSP tasks listed above.

The strength of the United States capability in performing criticality safety analyses resides in the diversity of three relatively mature Monte Carlo codes: the KENO/SCALE codes at ORNL, the MCNP code at LANL and the VIM code at ANL. The KENO codes, which employ the fast but approximate energy multigroup approximation, have been in production use for criticality safety analyses for over three decades. The more general neutral particle transport codes, MCNP and VIM, employ the more rigorous continuous-energy representation in a direct physics analog of the neutron-nucleus interactions and particle kinematics. For both production analysis and benchmarking applications, the fully independent solution algorithms, including the processing of cross sections, utilized by these three code systems provide a redundant, corroborative capability free of common mode failure.

The need or justification for this independent, redundant, corroborative capability is best illustrated by a recent benchmark activity involving the application of the three Monte Carlo codes: KENO, MCNP and VIM. Specifically, ANL submitted the U-Fe benchmark solution to the ICSBEP (see Section 4.0), which showed discrepancies in k-effective of greater than 10% in some cases. From the analyses, the ICSBEP personnel and individuals responsible for analytical methods at ORNL were able to identify the problem (i.e., cross-section processing) and quickly perform the necessary corrective actions. Moreover, this redundant capability is required when experimental data are lacking and it is necessary to extend the analytical bias beyond the range of experimental conditions over which the bias has been established. As recommended in Section 4.3.2 of ANSI/ANS- 8.1[8]: *"where the extension is large, the method should be supplemented by other calculational methods to provide a better estimate of the bias, and especially of its uncertainty in the extended area (or areas), and to demonstrate consistency of computed results*."

6.2 Departmental Requirements

In addition to the regulatory requirements described in Section 1.3, Departmental programmatic requirements arise from the large quantity and wide variety of fissile material operations being conducted or in the planning stage. The overall scope of these requirements is illustrated by the fissile inventory, which includes:

- hundreds of tons of highly enriched uranium (HEU) and weapons grade plutonium;
- over 100,000 commercial reactor fuel assemblies;
- thousands of naval, production, research, demonstration and test reactor assemblies;

- hundreds of thousands of drums containing fissile waste;
- hundreds of millions of gallons of fissile waste in tank storage.

The handling, processing, storage and ultimate disposition of this material quite often involve situations lacking satisfactory validation and qualification of analytical methods and data. Deficiencies in experimental benchmarks and nuclear data are being addressed by other tasks of the NCSP (see Sections 4 and 5). The majority of the work under the Analytical Methods task is the maintenance of the capability or infrastructure needed to develop and refine calculational methods. However, certain parts of the needed improvements will also improve the qualification of these methods for new applications, thereby reducing risks and operating costs. Demonstrated analytical precision is highest for design conditions involving reactor fuel and weapons components. However, the vast majority of new DOE applications involve material conditioning and long-term storage in geologic media. Improvement and qualification of the analytical methods and data will substantially enhance DOE efforts in meeting both its procedural and programmatic requirements for these new missions.

6.3 Program Objectives

The primary objective of the Analytical Methods task is to provide independent, redundant capability for corroborative analyses in production and benchmarking applications, and to maintain the capability within the DOE to do such work. Therefore, during the first three years of this program, priority has been given to infrastructure considerations, such as capability maintenance, plus training and user assistance. Capability maintenance has been budgeted at 0.9 full-time equivalents (FTEs) under Subtasks 1, 2 and 3. With recognition of the limited number of VIM users, the training and user assistance activity has been budgeted at 0.8 FTEs for Subtasks 1 and 2, and 0.1 FTEs for Subtask 3. Beginning in FY 1999, RSICC is being funded to perform Subtask 4. Substantial progress has been made in all subtasks, and given the prospect for continuing stable funding, DOE is meeting the primary objective of this task.

The secondary objective of this task is to upgrade the software to make improvements needed to overcome known deficiencies in handling certain types of applications. Generally, these applications fall in the intermediate energy range under partial neutron moderation and/or they involve loosely coupled fissile units with known problems in fission-source convergence. Experiments to qualify the methods for these applications include the ZEUS intermediate-energy critical experiments and the planned experiments that address large arrays of small units (see Section 3). For the KENO/SCALE software, the top-priority enhancements have been in the area of resolved-resonance shielding, utilizing modern ENDF/B-VI data and more rigorous transport models regarding geometry-material combinations. For the MCNP software, the top-priority enhancement has been the development and implementation of a problem-dependent unresolved-resonance shielding capability, utilizing the probability table method. At ANL, the top-priority enhancement has been an effort to address the fission-source convergence problem through stratified sampling. These work areas have been supported through multiple sponsors and by accommodating staff time out of the primary objective. Some progress has been made in all three areas. However, absent additional funding, progress in code enhancements will continue to be slow. (see Section 6.6).

6.4 Accomplishments

6.4.1 Subtask 1 – KENO/SCALE Work at ORNL

Capability maintenance included software upgrades for operation on modern computing platforms and under modern compilers. Also, software bugs were investigated and fixed.

Training and user assistance included two SCALE/KENO four-day workshops and one KENO-VI tutorial per year. Also, approximately 400 efforts per year were expended in providing advice regarding input specifications, geometry modeling and interpretation of results.

Administrative and technical support included progress reports, a Field Work Proposal and updates to the Five-Year Plan. Recently, substantial ORNL effort was expended in presenting the benefits of the NCSP to DOE/ORO/EM Management. As part of the DOE/EH-sponsored work funded under this task, ORNL staff assist in organizing the Annual NCTSP Workshop, including chairing sessions and conducting surveys. Also, ORNL Staff participated in the development of professional consensus standards (national and international) and represented the United States in OECD-NEA criticality safety activities.

6.4.2 Subtask 2 – LANL Work on the MCNP Code and Associated Software

Capability maintenance included assurance of MCNP compatibility with new computer hardware, operating systems, graphics libraries, and parallelization libraries (PVM, MPI), user support, investigation of bug claims, bug fixes, software quality assurance, and documentation. A criticality verification test suite of analytic transport solutions was compiled and documented.

Training and user assistance included four MCNP four-day courses and approximately 400 efforts per year in providing advice regarding input specifications, geometry modeling and interpretation of results.

Management support included LANL staff participating in the NCSP planning meetings and program reviews.

6.4.3 Subtask 3 – ANL Work on the VIM Code and Associated Software

As part of capability maintenance, beginning in FY 1997 the VIM Code was made available to the criticality safety community and a User's Manual was developed. The VIM Code is available from RSICC.

Training and user assistance included a presentation on VIM capabilities at the September 1997 Criticality Safety Topical Meeting. VIM is being applied as one of the benchmarking codes in the ICSBEP. VIM user assistance involves providing advice regarding input specifications, geometry modeling and interpretation of results.

Progress has been made in the application of stratified sampling techniques for treating the fission source convergence problem. A comparison with the superhistory powering technique has been performed, and specifications for two benchmark convergence problems are being developed.

Management support included ANL staff participating in NCSP planning meetings and program reviews and representation of the United States in OECD-NEA criticality safety activities.

6.4.4 Subtask 4 – Collection, Packaging and Dissemination of Software by RSICC

During the first two years of the NCSP, the RSICC packaged SCALE 4.4 containing KENO-V.a and KENO-VI, the prototypic software MCNP4XS (restricted to a limited distribution), and a production version of VIM. RSICC co-sponsored a series of code workshops and distributed numerous copies of criticality safety codes as a direct result of the workshops. Table 6-1 lists the recent workshops, number of attendees and number of code packages distributed following the workshops.

Table 6-1. Recent RSICC Co-Sponsored Workshops

Name of Workshop	Date of Workshop	Number of Attendees	Number of Codes Distributed
LANL MCNP	March 10-13, 1998	13	
DORT TRANSPORT	April 24-25, 1998	27	26
SCALE KENO-VI	April 27-30, 1998	17	
JAPAN MCNP	May 11-15, 1998	18	
LANL MCNP	June 2-5, 1998	22	22
LANL MCNP	August 10-14, 1998	22	
ORNL MCNP	September 21-25, 1998	22	
ORNL SCALE	October 27-30, 1998	21	
ORNL SCALE	November 5-8, 1998	17	
DOE MCNP	March 15-19, 1999	15	
MCNP	March 23-26, 1999	5	
MCNP VISED	March 15-18, 1999	15	
	Total	230	48

6.5 Budget And Schedule

The following table is a summary of FY 2000 through FY 2002 activities and minimum budget requirements for the Analytical Methods task of the NCSP.

Table 6-2. Schedule and Budget for the Analytical Methods Task of the NCSP			
Tasks by Laboratory	Deliverables and Budget *		
	FY 2000 ($k)	FY 2001 ($k)	FY 2002 ($k)
Oak Ridge National Laboratory			
Subtask 1 KENO/SCALE software - capability maintenance, training and user assistance, administrative and technical support Needed improvements – documentation and release of SCALE/CENTRM sequence; compatibility of KENO3D graphics with KENO-VI geometry; determination and utilization of material region and zone volumes in KENO.	426 (continuing)	426 (continuing)	426 (continuing)
Subtask 4 RSICC collection, packaging and dissemination of criticality safety software (codes and cross-section libraries)	200 (continuing)	200 (continuing)	200 (continuing)
Los Alamos National Laboratory			
Subtask-2 MCNP and associated software – capability maintenance, training and user assistance, management support Needed improvements – JUSTINE graphics and input processing including repeated structures, CAD.	384 (continuing)	384 (continuing)	384 (continuing)
Argonne National Laboratory			
Subtask-3 VIM and associated software – capability maintenance, training and user assistance, management support Needed improvements – completion of stratified sampling, graphics and GUIs for VIM	293 (continuing)	293 (continuing)	293 (continuing)
Task Total:	1303	1303	1303
* Budget amounts listed in constant FY 1997 dollars.			

The total estimated funding requirements for the years FY 2003 and FY 2004 are given in Table 6-3.

Table 6-3. Estimated Out-Year Funding* for the Analytical Methods Task of the NCSP	
Year	Budget ($k)
2003	1303
2004	1303
*Budget amounts listed in constant FY 1997 dollars.	

6.6 Extended Work Opportunities

The qualification of analytical methods and data for new DOE applications will require a higher level of activity in this task. As new nuclear data and critical experimental benchmarks become available, additional activities will include the generation of new cross-section libraries, more extensive validation against experiments and studies to develop an improved understanding of the basic physics which are encoded within the methods.

The timetable for integrating the new nuclear data, experimental benchmarks and sensitivity and uncertainty capabilities from the AROBCAD task into an overall qualification of analytical methods and data for DOE applications has a target of FY 2008 for full capability. In addition to the extensive validation exercises utilizing the new cross section libraries and benchmark critical experiments, the results of the sensitivity and uncertainty work under the AROBCAD task will indicate where better transport modeling of the neutron kinematics is needed. To support these improvements, a graduated increase in the Analytical Methods task effort from approximately two FTEs to four FTEs per site will be required.

In addition to the needed improvements shown in Table 6-2, high-priority work at the three sites includes: 1) ORNL - development of an ENDF/B-VI based criticality safety multigroup library including utilization in the ICSBEP Task, spectral indicies consistent with ICSBEP; 2) LANL - fission source and macro-body specifications, delayed neutron physics, spectral indicies consistent with ICSBEP, automatic geometry testing and enhanced user warnings; and 3) ANL - VIM fuel cycle analysis including energy and temperature interpolation of data, enhanced statistical testing and spectral indicies consistent with ICSBEP.

Potential out year improvements in analytical methods at ORNL include perturbation capabilities with KENO-VI, an energy point-wise version of KENO, and extension of the flexible-geometry NEWT discrete-ordinates transport software from two- to three-dimensional geometries. Similar work has been proposed for the deterministic software at LANL, one task being the utilization of first-collision source ray-tracing with DANT for treating arrays of fissile units. Another long-standing proposal by LANL is the development of a suite of statistically determined parameters to characterize benchmark criticals relative to fissile applications. Proposed work at ANL includes the generation of problem-dependent cross section libraries with VIM and the optimization of the VIM algorithms for operation on massively parallel computer architectures.
Activity in subsequent years will include software capability maintenance, training and user assistance.

6.7 Points of Contact

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7.0 Applicable Ranges of Bounding Curves and Data

7.1 Introduction

The objectives of the AROBCAD project are to couple the DOE NCSP Critical Experiments, Benchmarking, Nuclear Data, Training and Information Dissemination tasks with standardized, "user friendly" analytical methods to permit the user and regulatory overseer to more objectively and technically justify margins of nuclear subcriticality for safety as well as the adequacy of benchmark critical experiments.

The AROBCAD task of the DOE NCSP provides ". . . a program to interpolate and extrapolate such existing calculations and data as a function of physical circumstances that may be encountered in the future, so that useful guidance and bounding curves will result"[10] as committed in the DOE Implementation Plan for the DNFSB Recommendation 97-2.[3] More particularly and primarily, the AROBCAD task provides a program to comply with the regulatory implementation[6, 7] of national consensus standards, specifically ANSI/ANS-8.1.[8]

The AROBCAD task provides for the development and implementation of mathematically sound sensitivity and uncertainty (S/U) analysis methods (i.e., first-order linear perturbation theory) and automated optimization methods to nuclear criticality calculations of benchmarks and safety-analysis applications. Both the S/U and optimization methods are to be developed, interfaced and refined within the SCALE[11] suite of codes.

The AROBCAD task has five technical subtasks that are identified to develop and demonstrate the terminal products, to include training, for the end user community, plus one administrative subtask. The subtasks are:

- Subtask 1 – implement use of optimization techniques for establishing bounding values;
- Subtask 2 – investigate anomaly and discrepancy effects relative to bounding values;
- Subtask 3 – investigate and apply quantitative methods for identifying experimental needs;
- Subtask 4 – develop guidance for interpolating and extrapolating bounding values;
- Subtask 5 – develop guidance for establishing bounding margins of subcriticality; and
- Subtask 6 – planning, administration, and reporting.

Subtasks 1 through 5 evolve through the development and demonstration stages of the AROBCAD program to the final documentation and distribution of the software and technology to the United States DOE user community.

The S/U methods application will allow evaluation of the validity and ranges of applicability when determining interpolated and extrapolated bounding curves or data for nuclear criticality safety. The S/U methods provide a theoretically rigorous methodology for evaluating the applicability and influence of materials and geometries impacting computational bias, bias trends, bias uncertainties, subcritical limits, and consistency with measurements for safety analysis applications. Conversely, the same S/U methods can provide a rigorous methodology to justify or deny the need for critical experiments as they could relate to nuclear criticality safety applications.

The optimization methods are to be used in the determination of bounding curves and data for the purpose of determining maxima or minima of nuclear material parameters. Specifically, the initial optimization methods to be pursued are material density and concentration oriented (in contrast with linear-dimension optimization). The method will provide four separate computational options for outputs and plots of:

- equal volume replacement effectiveness functions of all the constituent in a given zone relative to the first constituent in that zone;
- equal cost (weight) replacement effectiveness functions of all the constituents in a given zone relative to the first constituent in that zone;
- maximization of k_{eff} for a given fissile material mass; and
- minimization of fissile material mass for a given k_{eff}.

The optimization methods have been applied to nuclear and radiation-shielding analytical methods, but prior and recent applications[12] have not provided for appropriate flux-weighted group cross section processing during the optimization processing nor have the methods been "user friendly" for common usage.

The developing and terminal products of the AROBCAD project provide some of the necessary capability (i.e., analytical infrastructure for theoretically and technically defining and defending the applicability of bounding curves and data) to assure and defend that adequate margins of subcriticality are applied for nuclear criticality safety in DOE non-reactor facilities and fissile material operations.

The products of the AROBCAD task interrelate to various DOE NCSP tasks as follows.

- Critical Experiments – The S/U and optimization software developments of AROBCAD will be useful for identifying needed critical experiments for nuclear criticality safety applications.
- Benchmarking – The S/U software developments of AROBCAD will be useful for comparative analysis with quoted experimental or measurement uncertainties. Such comparisons will assist in the verification of the AROBCAD methods as well as the evaluations of the benchmarks.
- Analytical Methods – As the S/U and optimization software matures and is documented it will be transferred to the Analytical Methods task for maintenance and issuance to the user community.
- Nuclear Data – As applied in the AROBCAD task, the S/U and optimization software products will interrelate with the Nuclear Data task as appropriate as discrepancies between computed results and experimental measurements are observed and reported to the Nuclear Data task for consideration and disposition.
- Training and Qualification – Throughout the development and final documentation of the AROBCAD software products, technical papers and reports will be provided to the potential user community for familiarization and training with the technology. Upon the transfer of the documentation to the Analytical Methods task, user training courses will be developed and offered through the Training and Qualification task of the NCSP.

- Information Preservation and Dissemination – There will be limited interaction between the AROBCAD task and the Information Preservation and Dissemination (IPD) task of the NCSP. As the products of the AROBCAD project mature, it is expected that the documentation of the products will become available or referenced by the IPD task.

The AROBCAD project will be managed by ORNL. It will continue, with appropriately approved adjustments/revisions, as described in the seminal technical program plan[13] that was reviewed by the DOE CSSG and approved by the DOE NCSPMT.

7.2 Departmental Requirements

The development and application of the AROBCAD project is a crucial task for the global requirements of the NCSP as given in Section 1.3. That is, development of the AROBCAD methodologies is an integral component of the technical infrastructure of the DOE criticality safety program.

In addition, the sensitivity and uncertainty techniques of the AROBCAD task of the NCSP will help provide the methods to permit justifiable applications of well or poorly benchmarked computations for safety applications such as

- environmental or non reactor nuclear facility remediation,
- waste disposal, and
- fissile material dispositioning programs

that involve fissile materials and commingled disposition or waste matrixes that are uncommon to the historic pursuits of the DOE and its predecessor organizations (i.e, weapons production facilities and designs, reactor concepts and designs), including the potential inadequate justifications for past waste disposal activities. The optimization methods provide for the development of a sound methodology for determining bounding curves and data with more than historic macroscopic evaluations with coarse perturbation analyses.

Both products of the AROBCAD, the S/U and optimization methods, provide the opportunity for improved operational efficiency and improved safety bases for customer needs but also the potential basis for regulatory penalties resulting from historic inadequate safety analyses.

Examples of Departmental requirements that can be addressed by the AROBCAD project are the determination of computational biases and uncertainties for establishing the areas of applicability and the appropriate bounding margins of nuclear subcriticality, as required by national standards, for the safety of all operations involving fissile materials outside reactors (i.e., fissile material storage, processing, dispositioning, transportation, and handling).

7.3 Program Objectives

The objectives of the AROBCAD project are to couple the DOE NCSP Critical Experiments, Benchmarking, Nuclear Data, Training and IPD with standardized "user friendly" analytical methods to permit the user and regulatory overseer to more objectively and technically justify margins of nuclear subcriticality for safety and the adequacy of benchmark critical experiments.

The AROBCAD project is to provide terminal products for independent user applications by FY 2005. Software product documentation, distribution, training and transfer to other tasks of the NCSP are to occur between FY 2006 and FY 2008. Prototypic demonstrations and applications of the AROBCAD methods will be provided throughout the developmental period of the project. The specific applications are directed at pertinent and current Departmental needs. Examples include assessments for the benchmarking applicability to the Hanford K-Basin waste transfer to storage tanks and the National Spent Fuel Disposition projects. Other Departmental objectives such as plutonium dispositioning and waste solidification and vitrification may be evaluated during the period of development. Of particular interest will be the use of benchmark criticality experiments and newly determined or developed nuclear data evaluations and associated covariance data. The S/U analytical method will be employed to examine and extrapolate critical experiment data along with other available benchmarks into areas which are applicable to program operations being analyzed. Examples include the range-of-applicability of U(90)/SiO_2 and Pu/SiO_2 criticality benchmark experiments that are to be performed during the development period of AROBCAD. The optimization methodologies will be applied to examine the minima and maxima of systems. The priority of efforts will be highly influenced by recommendations about the programmatic safety needs of the DOE as interpreted by the DOE CSSG and NCSPMT. The use of the S/U and optimization methods after FY 2006 will be the responsibility of the intended users (i.e., contractor and DOE oversight safety personnel). Beyond FY 2006, however, scheduled and impromptu tutorials and user assistance are expected to be provided through the IPD, Training, Development and Qualification, and Analytical Methods tasks of the NCSP.

7.4 Accomplishments

The AROBCAD project has had seminal development through a recent United States NRC project[14] which has demonstrated applicability to a trial set of benchmark experiments. Though an objective of the United States NRC project was to examine the influence of slightly increased enrichments of uranium (i.e., ^{235}U enrichments upwards of 10 weight percent from the Advanced Vapor Laser Isotope Separation process), greater sensitivities and concerns were discovered for poorly moderated systems (e.g., hydrogen to ^{235}U ratios less than 15).

The project has not progressed long enough to apply and demonstrate the value of the optimization methods for determining bounding curves and data.

7.5 Budget and Schedule

Task completion and schedule is provided in the September1998, Revision 4, Technical Program Plan for AROBCAD. The near-term schedule is given in Table 7-1.

As previously discussed, budgets and deliverables beyond FY 2002 are focused on the final documentation, dissemination, demonstration/training applications, and transitioning to the other formal US DOE NCSP tasks. The total estimated funding requirements for the years FY 2003 and FY 2004 are given in Table 7-2.

Table 7-1. Schedule and Budget for the AROBCAD Task of the NCSP			
	Deliverables (all delivery dates are 9/30 of cited FY)		
Task	FY 2000 ($k)	FY2001 ($k)	FY2002 ($k)
1) Implement use of optimization techniques for establishing bounding values .	150	150	100
	Technical report on the expanded optimization theory, implementation approach, and prototypic testing.	Development of SCALE optimization sequence: a) documentation of sequence within SCALE; b) sequence pre-production version to requesting users; c) determination of minimum critical parameters for selected applications	a) Release of sequence to RSICC within SCALE-5 b)Technical report with guidance and illustrative applications. Include recommendations to use expanded optimization process for design of experiment/operation.
2) Investigate means to resolve or incorporate anomaly and discrepancy effects into bounding values.	200	205	205
	Technical report on investigation of neutron slowing down & leakage discrepancies in NIST experiments.	a) Technical report on S/U analysis of epithermal systems. b) Initiate study of loosely coupled uranyl nitrate units	Technical reports on S/U analysis of uranyl nitrate arrays and US vs. French experiment anomalies.
3) Investigate utilization of S/U and statistical methods for identifying experimental needs (i.e., critical or near critical and cross section)	150	100	100
	Initiate studies using application(s) of interest to DOE (e.g., Hanford Waste Tanks, and plutonium salts)	Technical reports discussing viability of approach and recommendations from applications.	Guidance report with demonstration using ^{233}U systems (or appropriate substitute).
4) Develop guidance for interpolating and extrapolating bounding values	90	100	150
	Technical report on parametric phase space appropriate for establishing bounding curves and data useful to the NCS community	Technical report demonstrating preparation and use of bounding curves and data using GLLSM approach.	Guidance report with examples pertinent to DOE applications.
5) Develop guidance for establishing bounding margins of subcriticality	65	100	100
	Report summarizing current approaches to characterizing acceptable margins of subcriticality.	Technical guidance on recommended statistical approach(es). Initiate investigation to combine S/U and statistical methods for defining bounding margins of subcriticality.	Technical guidance for incorporating S/U analyses with statistical approach to define bounding margins of subcriticality.
6) Planning, administration, and reporting	45	45	45
	Budgeting, scheduling, planning, quarterly progress reports, etc.	Budgeting, scheduling, planning, quarterly progress reports, etc.	Budgeting, scheduling, planning, quarterly progress reports, etc.
Total	700	700	700

Table 7-2. Estimated Out-Year Funding for the AROBCAD Task of the NCSP	
Year	Budget ($k)
2003	700
2004	700

7.6 Extended Work Opportunities

As NCSP circumstances and fiscal support present windows of extended work opportunities before the completion of the AROBCAD program, the program will seek to coordinate the products and enhancements of the S/U and optimization codes developments and applications with the other NCSP tasks. An example might include unforeseen generic input/output computer code refinements for the design and analysis of benchmark experiments, evaluations of experiments, and specialized applications to improve the areas of applicability to safety evaluations and the determination of bounding curves and data.

Currently, the AROBCAD program includes the necessary subtasks to bring the program to its conclusion by FY 2008. These subtasks are planned to exchange and supply useful information among other NCSP tasks so that the S/U and optimization code developments and documented demonstration applications occur in an organized fashion to benefit the other NCSP tasks. The merits of unforeseen potential opportunities will be assessed as they occur for consideration as adjuncts to the planned AROBCAD program.

7.7 Points of Contact

DOE Program Manager:	H. C. Johnson Nuclear Material Stabilization Office, EM-66 United States Department of Energy Telephone: 202-586-0191
Contractor Project Manager:	C. M. Hopper Oak Ridge National Laboratory Nuclear Engineering Applications Computational Physics and Engineering Div. Telephone: 423-576-8617

8.0 Information Preservation and Dissemination

8.1 Introduction

The Information Preservation and Dissemination (IPD) task of the NCSP is a program to preserve primary documentation supporting criticality safety and to make this information available for the benefit of the technical community. This primary information includes not only experimentalists' logbooks, notes, drawings, photographs, and material descriptions from those sites at which critical experiments were conducted in the past but also company reports and internal memoranda which might be of benefit to future criticality safety engineers.

There are two major subtasks within the IPD task of the NCSP:

1) the Criticality Safety Information Resource Center (CSIRC), which is tasked with collecting and preserving the multitude of documents directly related to critical experiments and criticality safety; and

2) the NCSP World Wide Web Internet site, which is the central focal point for access to criticality safety information collected under the NCSP subtask, and the gateway to a comprehensive set of hyperlinks to others sites containing criticality safety information resources.

8.1.1 CSIRC

There is a threefold benefit of this preservation and dissemination effort: the uncovering of original experimental results which had not previously been reported; the sharing of information to minimize duplication (of experimental results and analytical evaluations) worldwide; and the training of new criticality safety engineers. Recently an effort was started to videotape some of the pioneers in the field to capture their thoughts and philosophies as to proper approaches to the practice of criticality safety.

CSIRC was formally funded for the first time in FY 1998 by the DOE as part of the integrated response to DNFSB Recommendation 97-2. Previously the program had been evolving and developing informally beginning in the mid-1980s with the sending of the logbooks from the former Brookhaven National Laboratory (BNL) Critical Mass Laboratory to the LANL Archives Center for preservation. There was a strong concern that these logbooks were vulnerable to misplacement or destruction at BNL and the realization that they might contain valuable, previously unreported, critical experiment descriptions and measurement results. In some instances even previously reported journal articles do not contain experiment descriptions in the detail desired for today's benchmark purposes and it has been proven to be practical to return to original logbooks and extract additional, valuable information,

After this initial collection was moved to LANL, the experimental logbooks and related records from the Rocky Flats and Hanford critical mass laboratories were sent to Los Alamos for preservation. As word of this co-location of logbooks spread, those in need of benchmark critical data, which was not available in published sources, began to come to Los Alamos to search for such data. Clearly, if "mining of the stockpile" is successful in uncovering required data, this activity is likely to be much less expensive and faster than performing new critical experiments.

8.1.2 NCSP Web Site

By establishing the NCSP web site, DOE intends to use the latest technology for rapid dissemination of criticality safety information. The web site is designed to be the focal point for DOE criticality safety activities without duplicating the efforts of other organizations. It will do this by a series of verified hyperlinks to sites containing the source of criticality safety information, such as the CSIRC web site at LANL. The NCSP web site is maintained at LLNL and its content is coordinated by the CSSG.

8.2 Departmental Requirements

8.2.1 CSIRC

As regulatory scrutiny and expectations become ever more stringent and the cost of large safety margins (in lieu of more relevant benchmark data) becomes less tolerable, the value of "mining the stockpile" of past experiments becomes more cost-effective. Similarly, the awareness and use of past (reports of) analyses is much more important not only as a time saver, but also as an instructional tool for the newer engineer. While in the past most criticality safety engineers had the opportunity to spend time performing critical experiments, today's criticality safety practitioners must learn largely from the documentation of their predecessors. The videotapes of the pioneers should prove valuable in this training effort also.

8.2.2 NCSP Web Site

It is important to the DOE that criticality safety information and news be distributed to the widest possible audience as rapidly as possible. The development of the NCSP web site is the response to that need. With the development of user-friendly tools to access and search the Internet, a central web site to coordinate information at numerous DOE sites offers a great advantage in the dissemination of nuclear criticality safety information to a wide audience. The NCSP web site is designed to not duplicate the information held at other sites, but only to present the reader with a structured set of links to those sites. This avoids duplication and maintenance of superceded versions of documents, and leads the reader, whenever possible, to the original source of the information. By maintaining communications with the CSSG, the NCSP web site manager is able to post NCS-related news items in a timely manner.

8.3 Program Objectives

8.3.1 CSIRC

Efforts are underway in FY99 to scan all logbooks stored at Los Alamos and those which are still maintained by LLNL and ORNL. These approximately 100,000 pages will be loaded onto the LANL Criticality Safety web site and will be available for electronic review by researchers worldwide.

Concurrently, it is planned to load electronic versions of general interest documents such as LA-12808, The Nuclear Criticality Safety Guide, and the in-progress update of the Review of Criticality Accidents, along with their approximately 200 references onto the CSIRC web site during the next two fiscal years. Relatedly, the first attempt at putting reference material particular to a site, in this case the Y-12 Plant, on the web site has occurred during FY 1999. While full documents from Y-12 are not yet available, the titles of a vast store of documents are already there. This previously published, but often difficult to find, information promises to be of value to current and future engineers as they often must otherwise duplicate efforts already undertaken.

Lastly, the videotaping of pioneers in the fields of criticality safety and critical experiments, often one and the same person, is proceeding. These videotapes will be made available first as "hard copy" and, as technology permits, on the web site. Their recollections and reflections should be valuable teaching tools and serve as original sources for the practices and operational philosophies that were subsequently codified in the ANS-8 National Consensus Standards.

The logbook scanning and availability on the Los Alamos web site is only the first step in mining this stockpile of historical information. A very labor-intensive effort, and one, which requires criticality staff time, will be the review and indexing of this scanned information. When the information is initially scanned it is not keyword searchable, and therefore, not user friendly. A follow-on effort, having the original experimenters review documentation for unreported data, has been very successful to date, but only minimally attempted. Significant effort by those who have personal and past professional contact with these experimenters will be required in many cases to entice them to review these logbooks. This is a labor intensive effort which, like the indexing mentioned above, can best be performed by those already practicing criticality safety, a resource in short supply.

The scanning and making available of past published documents, company reports, and internal criticality safety evaluations on the web site will prove exceedingly valuable if this wealth of documents is searchable by keyword. It is not yet clear how large or time-consuming an effort this might be, but it is definitely worthwhile to pursue.

Either linking to foreign web sites that have information holdings similar to CSIRC or importing such information onto the CSIRC web site is expected to be of major benefit to the worldwide community. The extent of this effort is largely unknown. Certainly there are criticality pioneers from other countries, particularly Britain, France, and Russia, whose recollections and reflections would be valuable to preserve on videotape.

One more small, but very significant, information set is the classified holdings, particularly from the nuclear weapons related facilities. The various tasks involved with making this information usefully available are essentially the same as those already accomplished or described above for the current, unclassified CSIRC program with one additional step - assuring proper declassification of the material is accomplished.

8.3.2 NCSP Web Site

The NCSP web site is intended to become the main DOE NCS reference site by maintaining a hierarchical structure of links to information useful to the NCS community. Included on the web site are:

- links to all major NCS web sites including DOE Orders, NRC, ANS and national laboratories;
- general help for new criticality safety professionals;
- collections of bibliographic references and validation experiments;
- listings of criticality safety working group and management team members; and
- a question-and-answer message board for the NCS community.

A major activity of the web site subtask is to add to the technical content of the site, including the latest important technical bulletins, lessons learned and tools to aid new practitioners in the field of criticality safety. Maintenance of the site is an ongoing activity needed to keep information current and respond to the needs of the web site users.

8.4 Accomplishments

8.4.1 CSIRC

As noted above, logbooks from BNL, Rocky Flats and Hanford critical experiments laboratories, as well as those from LANL, have been collected at the LANL Archives Center for preservation and use by the criticality safety community. Logbooks from LLNL and ORNL are being preserved at their respective sites until indexing and scanning can be accomplished.

Reviews of logbooks from Rocky Flats and ORNL by original experimenters have resulted in the discovering, further documenting, and publishing of benchmark quality information. The material gleaned from the Rocky Flats logbooks in particular was of such high quality that it has already been peer reviewed and accepted by the ICSBEP. While difficult to quantify, the value of this information in an era of ever increasing costs for nuclear research, a lack of facilities in which to perform such, and tightening budgets, is enormous.

8.4.2 NCSP Web Site

The NCSP web site was built upon the earlier Nuclear Criticality Safety Center web site at LLNL, and is now operational at http://ncsc.llnl.gov:8080/. The master index is in place for simple navigation through the site, and a search capability was established to assist in using the on-line reference materials. Links to key DOE, NRC and other sites with criticality safety information have been added. Refinements and additional material continue to be added to the site.

8.5 Budget and Schedule

The pace of some of this work has significant urgency, while other parts may not. As the pioneers and original experimenters dwindle in numbers and the memories of those remaining fade, irrecoverable loss occurs. Thus, the allocation of funds to support the review of logbooks by original experimenters, where practical, and the videotaping of pioneers recanting the historical evolution of what have become accepted practices and in many cases regulatory norms will be given priority. The DOE and the NRC are each providing funding to achieve CSIRC objectives. The planned funding levels shown in Table 8-1 for both the DOE and NRC represent a level sufficient to continue to achieve meaningful progress. Should the planned funding level not materialize, this program plan and associated milestones will be revised accordingly.

Table 8-1. Schedule and Budget for the Information Preservation and Dissemination Task of the NCSP

	Deliverables		
Task	FY 2000 ($k)	FY2001 ($k)	FY2002 ($k)
CSIRC	50 + (50)[1]	50 + (50)[1]	50
1) Locate, secure, scan, review, index and make available on the CSIRC Web site logbooks, notes drawings, photographs and material descriptions from those sites at which critical experiments were conducted including relevant company reports and internal memoranda. A) Scan material to create electronic versions: B) Review and index scanned material to allow word search capability.	A) Scan logbooks located at LLNL (12/99) and LANL (9/00). Scan other documents at LANL, ORNL and LLNL (ongoing). B) Review and index logbooks located at LLNL and LANL (9/00). Review and index other documents at LANL, ORNL and LLNL (ongoing).	A) Scan other documents at LANL, ORNL and LLNL (ongoing). B) Review and index logbooks located at ORNL (9/01). Review and index other documents at LANL, ORNL and LLNL (ongoing).	A) Scan other documents at LANL, ORNL and LLNL (ongoing). B) Review and index other documents at LANL, ORNL and LLNL (ongoing).
2) Interview and videotape criticality safety pioneers and preserve this information for future use and benefit. Index videotapes to allow key word search capability. Make this information available on the CSIRC web site.	Interview and videotape criticality safety pioneers at LANL (ongoing)	Interview and videotape criticality safety pioneers at LANL (ongoing)	Begin to load videotapes on the CSIRC web site (ongoing).

3) Scan and place key reference documents on the CSIRC web site and make this information available on CD-ROMs. Place videotapes of pioneers on the CSIRC web site, technology permitting.(all LANL)	Scan and load LA-12808 and all 147 references in the document on the CSIRC web sire with search capability (3/00) Make LA-12808 and all 147 references in the document available on request on CD with search capability (6/00)	Load the updated Criticality Accident Report on the CSIRC web site (12/00) Scan and load all references to the updated Criticality Accident Report on the CSIRC web site (3/01) Make videotapes of the pioneers in nuclear criticality safety available on the CSIRC web site, technology permitting (9/01)	Continue indexing and loading information on the CSIRC web site (ongoing)
4) Coordinate the progress and information from the above tasks with the Benchmark program for the purpose of updating Benchmarked data. (LANL & INEEL)	Coordinate data with ICSBEP (ongoing)	Coordinate data with ICSBEP (ongoing)	Coordinate data with ICSBEP (ongoing)
NCSP Web Site	60	60	60
1) Maintain and update the NCSP web site as needed and provide status reports.	1. Update data on site: CSSG and NCSPMT announcements and meeting notes; NCS news items and information; remove obsolete items, etc. (ongoing)	1. Update data on site: CSSG and NCSPMT announcements and meeting notes; NCS news items and information; remove obsolete items, etc.	1. Update data on site: CSSG and NCSPMT announcements and meeting notes; NCS news items and information; remove obsolete items, etc.
2) System maintenance	1. Data backup , system maintenance, etc. (ongoing) 2. Message board maintenance and response to user problems (ongoing) 3. Task management reports: quarterly, monthly and conferences (ongoing)	1. Data backup , system maintenance, etc. (ongoing) 2. Message board maintenance and response to user problems (ongoing) 3. Task management reports: quarterly, monthly and conferences (ongoing)	1. Data backup , system maintenance, etc. (ongoing) 2. Message board maintenance and response to user problems (ongoing) 3. Task management reports: quarterly, monthly and conferences (ongoing)
DOE Total:	110	110	110
(1) Additional NRC funding in parentheses.			

Similar tasks will continue during the years 2003 and 2004. The total estimated funding requirements for the years FY 2003 and FY 2004 are given in Table 8-2.

Table 8-2. Estimated Out-Year Funding for the Information Preservation and Dissemination Task of the NCSP		
	Budget ($k)	
Project	FY 2003	FY 2004
CSIRC	50	50
NCSP Web Site	60	60
Total	110	110

8.6 Points of Contact

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9.0 Training and Qualification

9.1 Introduction

The Training, Development and Qualification (TDQ) activities of the NCSP were developed in response to the statement by the DNFSB in Subrecommendation 6 of Recommendation 97-2[1], that the proposed new hands-on course at Los Alamos National Laboratory should "serve as the foundation for a program of formal qualification of criticality engineers."

Well-trained criticality safety personnel form the key to maintaining the high standard of quality that must be applied to every aspect of the NCSP. The TDQ task is therefore an integral component of the criticality safety infrastructure of the DOE and affects every other task of the NCSP by providing the guidance and resources necessary to maintain the training and qualification of the specialists performing work in the other tasks of the Program. The TDQ task has three subtasks:

1) Continue to offer hands-on training courses at LANL, including the new five-day course, as needed by DOE;
2) Identify training needs, and the resources to meet those needs, developing new resources in areas where no suitable materials exist; and
3) Develop standard qualification programs for both federal and contractor criticality safety personnel.

The goal of the TDQ task can be summarized by the first of three action statements in the Executive Summary of the DOE Implementation Plan[3] for DNFSB Recommendation 97-2.

> Improve the technical knowledge of criticality safety personnel. This will be accomplished by updating and improving the training offered at DOE's critical experiments facility, improving site training and qualifications programs by identifying and incorporating best practices, and by identifying exceptional criticality safety curricula offered at institutions outside the Department.

While most criticality safety staff members have a background in nuclear engineering, nuclear physics or a related field, NCS staff must also understand the fissile material processes, human factors, and anticipated process upsets to develop proper criticality safety controls. This knowledge is not gained by university training. The Department has developed a new course and identified existing specialized courses that present hands-on, real-world applications of criticality safety principles.

The benefits to the DOE from having comprehensive criticality safety programs with well-trained staff members should be obvious. Among the benefits will be an immediate increase in the efficiency of operations involving fissile materials. When doing evaluations to support the handling, storage and transportation of fissile materials, a well-trained staff will know the proper analysis techniques to use for a given situation. By learning that a thorough understanding of operations is necessary, and how to properly interface with the operations staff, criticality safety evaluations of those operations can support efficiency as well as safety. Above all, the proper training will instill the correct philosophy of criticality safety that will allow the practitioner to know what factors are important to criticality safety and how to develop the proper controls without being overly conservative to the point of restricting operations with no added safety benefits. Regulatory requirements can then be met in a way that minimize the impact on operations.

9.2 Departmental Requirements

In addition to the requirements of DOE Orders and Standards discussed in Section 1, it is essential that DOE operations be conducted by personnel who are competent and skilled in the application of their knowledge to both the analytical and operational aspects of nuclear criticality safety. One method to achieve this goal is through training and periodic retraining of criticality safety personnel, and formal verification of this training through the establishment of a rigorous qualification program.

As experienced criticality safety practitioners leave the field, there are fewer opportunities for entry-level staff to participate in long-term mentor programs to gain first-hand knowledge of practical criticality safety. However, the DOE must still provide an infrastructure wherein criticality safety staff members are able to gain and maintain a level of training commensurate with the responsibilities of their positions. The TDQ subtasks of the NCSP address this requirement by:

1) providing hands-on training courses where students actively participate in approach-to-critical experiments and see first-hand the effects of material interactions on the reactivity of various configurations;

2) identifying training resources, promoting the development of new training materials to supplement existing curricula and working with other organizations to quickly respond to training needs as new programs apply criticality safety to areas requiring new information; and

3) developing and implementing a uniform criticality safety qualification program for criticality safety staff throughout the DOE complex.

9.3 Program Objectives

The basic objective of the TDQ task of the NCSP is to provide criticality safety practitioners with the guidance, and to the extent possible, the tools to become properly trained in the wide variety of subjects that comprise the field of criticality safety.

One subtask of the TDQ task is to provide hands-on courses at LANL for both managers and practitioners. As noted in Section 9.1, a second five-day course was developed under the NCSP and will be fielded in FY-2000. The original five-day course and the three-day course will continue to be offered.

The TDQ task included an initial survey of training needs as perceived by criticality safety organizations and practitioners, then to match those needs, if possible, to existing training courses at DOE facilities, universities and colleges. In those areas where training does not exist, a program was to be initiated to develop materials to meet those needs. In a parallel effort, the identified training areas were used to develop the DOE criticality safety qualification standard, which will be used to implement qualification programs at DOE sites.

Reviews of training needs and site qualification programs shall be performed annually in order to respond to the changing needs of the criticality safety community. These reviews will gather information and feedback from the CSCT, which has members from each of the DOE field offices, and the Criticality Safety End-Users Group, which has representatives from the majority of the DOE contractor facilities. The review of site qualification programs is expected to be an ongoing process of interaction with the site criticality safety and training organizations in order to help establish and maintain uniform qualification programs across the DOE complex.

Each year identified training needs will be cross-referenced to available resources and the results of the work will be made available to the user community. It is expected that not all training needs will be covered by existing resources, so another part of the TDQ Program is to arrange for the development of training materials in those areas where either none exist or exist only in a location or format suitable for use by a small number of people. This development program has already begun, and will be routinely reviewed as the work is being done. One goal of the development program is to produce modular tools that can be used by site training organizations or by individuals for self-study programs as part of the site qualification program.

An annual review of the need for new training materials will be conducted and correlated to the training needs identified by the CSCT and the CSSG. The results will be used to develop a list of required new training materials. The same resources will be relied upon to determine the suitability of the DOE qualification program standard. Responses will be compiled and reviewed by the CSSG who will forward prioritized recommendations for TDQ task activities to the NCSPMT.

9.4 Accomplishments

Under the NCSP, a new five-day, hands-on training course has been developed. This course is complementary to the original five-day course and together they present the criticality safety practitioner with a good overview of proper handling of fissile material through a series of actual experiments, plus on-site reviews and discussions of several active fissile-material operations.

The CSSG has completed the initial survey of nuclear criticality safety training needs and available courses[15] based on a job task analysis of the general criticality safety staff member. This activity identified a lack of training resources in a number of areas, including neutronics, hand calculations and verification and validation. While some of these topics are available in a diffuse format in university courses, it was decided to pursue the development of training modules that could be distributed to the criticality safety community for use in on-site training classes.

The first set of modules in the Nuclear Criticality Safety Engineer Training (NCSET) program have been written and are being placed on the NCSP web site as they are completed. These modules include introductory neutronics (fission, neutron interactions, chain reactions, scattering and thermalization), criticality limits, transport and diffusion theory and Monte Carlo methods. Additional modules have been outlined to cover the topics of hand calculations and verification and validation, and will be developed within the year.

Development of these modules is seen as the first step in creating a training program that will supplement the courses available from DOE or university sources and become the basis for training by on-site organizations. This program will provide consistency across the DOE complex, allow training without the expense of travel and extended absence from work, and will interface with both the DOE and contractor qualification programs that are being developed in parallel with the training modules.

A criticality safety qualification standard[16] for federal criticality safety personnel was developed and reviewed by the CSSG. This standard is currently in the formal DOE review process. A draft of the guidance for contractor criticality safety qualification programs[17] has been written and is currently undergoing a broad-based user review before being issued as a formal DOE directive.

9.5 Budget and Schedule

Table 9-1 presents the budget and schedule for the TDQ task of the NCSP. It is assumed that six three-day courses and one each of the two five-day courses will be offered each year at the Los Alamos Critical Experiments Facility. Demand has been such that this schedule is expected to be adequate for the foreseeable future.

Table 9-1. Schedule and Budget for the Training Development and Qualification Task of the NCSP			
	Budget and Deliverables		
Task	FY 2000 ($k)	FY2001 ($k)	FY2002 ($k)
1) Continue to offer hands-on training courses at LANL, including the new five-day course, as needed by DOE.	200(1)	200(1)	200(1)
	1. Conduct six three-day hands-on courses (ongoing) 2. Conduct two five-day hands-on courses (one of each type) (ongoing) 3. Review the results and update the LACEF training program as necessary (9/00) 4. Provide progress reports to the CSSG and NCSPMT (quarterly)	1. Conduct six three-day hands-on courses (ongoing) 2. Conduct two five-day hands-on courses (one of each type) (ongoing) 3. Review the results and update the LACEF training program as necessary (9/01) 4. Provide progress reports to the CSSG and NCSPMT (quarterly)	1. Conduct six three-day hands-on courses (ongoing) 2. Conduct two five-day hands-on courses (one of each type) (ongoing) 3. Review the results and update the LACEF training program as necessary (9/02) 4. Provide progress reports to the CSSG and NCSPMT (quarterly)
2) Identify training needs and resources; develop new resources in areas where no suitable materials exist.	47 (2)	47 (2)	47 (2)
	1. Perform an annual review and assessment of criticality safety training needs within the DOE complex (9/00) 2. Develop new training materials in response to the training needs assessment (9/00) 3. Coordinate development of new training materials and perform annual review and assessment of those materials (9/00) (3)	1. Perform an annual review and assessment of criticality safety training needs within the DOE complex (9/01) 2. Develop new training materials in response to the training needs assessment (9/01) 3. Coordinate development of new training materials and perform annual review and assessment of those materials (9/01) (3)	1. Perform an annual review and assessment of criticality safety training needs within the DOE complex (9/02) 2. Develop new training materials in response to the training needs assessment (9/02) 3. Coordinate development of new training materials and perform annual review and assessment of those materials (9/02) (3)
3) Develop and promulgate standard qualification programs for both federal and contractor criticality safety personnel.	3	3	3
	1. Perform annual reviews and assessments of site criticality safety qualification programs (9/00)	1. Perform annual reviews and assessments of site criticality safety qualification programs (9/01)	1. Perform annual reviews and assessments of site criticality safety qualification programs (9/02)
Total	250	250	250

(1) Supplemented by $84k from tuition collection.
(2) Budget split is: $5k to perform the annual review and assessment of training needs; $35k to develop new training materials; $7k to coordinate development of the materials and perform an annual assessment of them.
(3) Quarterly progress reports to be provided in the first three quarters of each fiscal year plus an annual report in the fourth quarter of each fiscal year

Similar tasks will continue during the years 2003 and 2004. The total estimated funding requirements for the years FY 2003 and FY 2004 are given in Table 9-2.

Table 9-2. Estimated Out-Year Funding for the Training Development and Qualification Task of the NCSP

	Budget ($k)	
Project	FY 2003	FY 2004
Hands-on Training	200	200
Training and qualification assessments, resource evaluation and development	50	50
Total	250	250

9.6 Points of Contact

DOE Program Manager:

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10.0 Example of Integrated NCSP Support for Departmental Programs

10.1 K Basin Sludge Removal Support

The NCSPMT was asked by EM to provide support to its Tank Waste Remediation System (TWRS) licensing for K Basin sludge processing at Hanford. Initial NCSP plans called for iron/plutonium benchmark experiments at Los Alamos, and evaluation and publication of the benchmark data in time to support TWRS licensing. However, in early May 1999, DOE decided that the K Basin sludge would be packaged and transported to the T-Plant for interim storage. The waste would then be combined with the M-91 waste streams for final treatment and disposal. This decision eliminated the need for iron/plutonium benchmark data. Even though the TWRS program no longer requires these data, iron/plutonium and iron/uranium benchmark experiments will remain on the priority experiments list because of the long-standing discrepancy between calculations and experimental data for these fissile systems and the number of DOE programs which could benefit from this work.

10.2 National Spent Nuclear Fuel Program Support

Fissile material in waste is frequently encountered in decontamination and decommissioning efforts, process sludge and settling tanks, in situ vitrification, and waste remediation efforts (including waste storage, retrieval, characterization, volume reduction, and stabilization). Presently, there are several sites in the United States in which fissile material has already migrated into a soil environment while others have the potential for such migration. The national geological repository at Yucca Mountain, Nevada is one example in which the gradual degradation of spent nuclear fuel and containment may eventually result in the migration of fissile material into the soil. The safety envelope for many fissile-bearing waste operations can be effectively defined by characterizing the waste matrices by major "non-neutron-absorbing" components. By neglecting impurities, the inclusion of which almost always results in a decrease in nuclear reactivity, conservative representations of waste matrices can be obtained. Silicon dioxide (SiO_2) is one of the more predominant and more reactive waste matrix materials that is encountered in typical dilute fissile contaminated waste systems, including Nevada tuft.

Even though criticality scenarios in most waste systems can be shown to be highly unlikely or incredible, it is always necessary to establish at what fissile material concentration criticality becomes a concern. Only when this information is known, is it possible to establish the likelihood of actually achieving such concentrations. It is therefore important that criticality safety analysts have confidence in the accuracy of their calculations. This confidence can only be gained through comparison of calculated results with experimental data. There are little or no experimental data available for most typically encountered waste matrix materials, including SiO_2.

Over the past three years the National Spent Nuclear Fuel Program, with the support of the INEEL Criticality Safety Organization and elements of the DOE NCSP has identified specific criticality safety issues associated with the proposed national geologic repository and have taken action to address these issues. Two of the issues identified by these organizations are:

(1) There are no critical experiments which have silicon dioxide as a principle constituent (similar to bounding soil conditions). Historical practice and experienced judgement indicate such experiments are highly desirable for validation of calculational methods and data used in support of the national geological repository at Yucca Mountain.

(1) The neutron absorber, gadolinium, is currently being considered for use inside some storage canisters to ensure the safety of those canisters. Additional data may be required to validate calculations associated with the use of gadolinium.

Actions taken to respond to these issues follow.

Critical Experiments And Benchmarking

Through DOE NCSP efforts, benchmarking facilities at the IPPE in the Russian Federation and at the LACEF were identified as facilities that could supply the SiO_2 data. Russia can provide silicon dioxide data with spectral characteristics that range from about 75% intermediate to about 75% thermal. The Planet assembly at LACEF can provide data at the extreme thermal end of the spectrum. Additional confirmatory data can be provided by the Comet (Zeus) facility at LACEF. The Comet facility can also serve as a back-up in the event that political conditions interfere with the planned experiments in the Russian Federation. Data for all of these experiments will be evaluated and documented by the ICSBEP and will be made available to the criticality safety community for application to all waste systems involving fissile contaminated soil or glass. The IPPE highly enriched uranium experiments and the LACEF Planet experiments should be completed by the end of fiscal year 1999. Additional plutonium data will be generated at IPPE early next fiscal year.

With regard to the potential need for gadolinium data, there are likely to be sufficient thermal homogeneous gadolinium data already available in the “International Handbook of Evaluated Criticality Safety Benchmark Experiments”. However, if the use of thin sheets of gadolinium or a plasma spray coating containing gadolinium is selected as a means of ensuring adequate criticality safety margins, additional experimentation may be necessary. In this event, the Planet facility at LACEF could provide these experimental data using thin foils of highly enriched uranium and foils of gadolinium and sheets of polyethylene. In the unlikely event that data for heterogeneous SiO_2, gadolinium, polyethylene and uranium systems are required, both the IPPE and LACEF facilities could be used to obtain these data.

Nuclear Data

In FY 1999, the Nuclear Data task of the NCSP will generate covariance data for the resolved resonance region for silicon isotopes and provide them to the AROBCAD task. Evaluated data for oxygen will also be completed and similar covariance files will be made available in FY 1999. The status of silicon capture cross-sections will also be assessed and, if needed, measurements can be made at ORELA in FY 2000.

In order to demonstrate its principles, AROBCAD is currently using an ENDF/B-V based multigroup library, which has been broadly validated for a wide variety of fissile material applications. Therefore, covariance data relative to ENDF/B-V evaluations are needed. (As soon as practical, AROBCAD will incorporate multigroup cross-section data and covariance files based on new evaluations provided by the Nuclear Data task.) In October 1998, the Nuclear Data task committed to providing, in a timely fashion, reasonable covariance data for use by the AROBCAD task in its initial development stage. ANL is leading the effort to assess and provide reasonable covariance data, with support from ORNL and LANL. The AROBCAD project has identified 19 materials (Note: 17 of these are already on the list of materials identified by criticality analysts for the Nuclear Data task) needed to address the needs associated with the disposition of spent nuclear fuel.

As part of the process, the Nuclear Data task organized and led a workshop in April 1999 to assess the status of covariance data in evaluated nuclear data files. An international group of about 30 experts attended and a number of needs and recommendations were discussed to remedy the current situation of poor quality and missing covariance data. One immediate outcome was the identification of a library of multigroup covariance data based on ENDF/B-V prepared in Europe (VITAMIN-J/COVA, with 175 neutron groups) that might be helpful in the preparation of "reasonable" covariance data for AROBCAD.

With regard to the potential need for gadolinium data, similar efforts to reevaluate the basic nuclear properties of gadolinium can be made if deficiencies in available data become evident.

Analytical Methods

The analytical methods (MCNP, SCALE/KENO, and VIM) supported by the NCSP are the tools used by the NSNFP for performing design studies and safety evaluations related to criticality safety. Staff from NSNFP have been provided technical support and training as needed relative to the use of the codes and data. The codes and data used by the analysts are made available via RSICC. RSICC also provided ANL with the VITAMIN-J/COVA multigroup covariance data to assist in developing initial covariance files for AROBCAD.

Applicable Ranges Of Bounding Curves And Data

Using input from the Nuclear Data and Analytical Methods tasks, AROBCAD methodology will be used to interpret the data obtained from the NSNFP benchmark experiments. The sensitivity of the experiments to the presence of SiO_2 will be evaluated and the range of applicability of the data will be established. The effects of the large copper reflector used in the LACEF experiments on the Comet assembly (Zeus) will also be assessed. As the AROBCAD methodology is developed further, it will provide a valuable tool that can be used to ensure that future experiments are designed to achieve the desired tests of materials and geometric properties.

Table 10-1 shows the planned schedule for NCSP activities to support the NSNFP.

Table 10-1. Schedule for NCSP Support to the NSNFP	
Activity	Completion Date
NSNFP -- Completion of the IPPE HEU / SiO_2 Experiments *(J. Blair Briggs)*	30 September 1999
NSNFP -- Review of available gadolinium data – Determination whether additional data are required to support the NSNFP, either available, but unevaluated data, new experimental data - *(J. Blair Briggs -- support provided by ISU)*	30 September 1999
AROBCAD -- draft report on the applicability of the IPPE & LACEF HEU / SiO_2 Experiment *(Calvin M. Hopper)*	30 September 1999
DATA -- New Capture Measurements for silicon at ORELA *(Robert W. Roussin)*	1 October 1999
DATA -- Provide covariance data for Si & O *(Robert W. Roussin)*	1 November 1999
NEW EXPERIMENTS --Design of HEU / Gd / CH_2 Experiments for LACEF Planet assembly *(J. Blair Briggs & Richard E. Anderson -- support provided by ISU)*	30 November 1999
ICSBEP -- Internally Reviewed Draft Evaluation of the IPPE HEU / SiO_2 Experiments *(J. Blair Briggs)*	30 November 1999
ICSBEP -- Independent Peer Review of the Draft Evaluation of the HEU / SiO_2 Experiments *(J. Blair Briggs)*	10 December 1999
AROBCAD -- draft report on the range of applicability of available gadolinium data and the additional data that can be provided by the LACEF gadolinium experiments on Planet *(Calvin M. Hopper)*	TBD
AROBCAD -- final report on the applicability of the IPPE & LACEF HEU / SiO_2 Experiments *(Calvin M. Hopper)*	31 January 2000
NCSP & NEW EXPERIMENTS -- Decision to perform HEU / Gd / CH_2 Experiment at LACEF *(NCSPMT)*	TBD
ICSBEP -- Completed HEU / SiO_2 Experiments Evaluation submitted to ICSBEP *(J. Blair Briggs)*	6 January 2000
AROBCAD -- final report on the range of applicability of available gadolinium data and the additional data that can be provided by the LACEF gadolinium experiments on Planet *(Calvin M. Hopper)*	TBD
DATA -- If it is determined that additional Gd data are need to support the NSNFP covariance data will be generated for Gd and, if needed, additional measurements will made at ORELA *(Robert W. Roussin)*	TBD

ICSBEP -- Working Group Review & Approval of IPPE HEU / SiO_2 Experiment Evaluation *(J. Blair Briggs)*	30 June 2000
ICSBEP – Internet Publication of the IPPE HEU / SiO_2 Exp. Evaluation *(J. Blair Briggs)*	31 July 2000
NEW EXPERIMENTS -- If it is determined that additional Gd data are needed to support the NSNFP and that the LACEF HEU / Gd / CH_2 experiments will provide the necessary information the experiments will be planned, performed, and documented in the form of a draft ICSBEP evaluation. *(Richard E. Anderson)*	TBD [a]
ICSBEP – Formal Publication of the IPPE HEU / SiO_2 Exp. Evaluation *(J. Blair Briggs)*	30 September 2000
ICSBEP – Evaluation of the LACEF HEU / Gd / CH_2 Experiments if they are required *(J. Blair Briggs)*	TBD
a. According to the current (June 1999) NSNFP schedule, criticality safety evaluation (including validation activities) must be completed by 31 July 2000. New data provided after that date would be used only as confirmatory data. However, if it is determined that the additional data from LACEF experiments are essential, a much higher priority on these data would be assigned. While a July 31 deadline is probably unrealistic, new gadolinium data from the Planet assembly could be provide by 30 September 2000. Based on preliminary surveys of existing gadolinium data, it is not likely that these data will be considered essential.	

11.0 References

1. Defense Nuclear Facilities Safety Board Recommendation 97-2, *Continuation of Criticality Safety*, May 1997.

2. Defense Nuclear Facilities Safety Board Recommendation 97-2, *Continuation of Criticality Safety*, May 1997.

3. Defense Nuclear Facilities Safety Board Recommendation 97-2, *Continuation of Criticality Safety*, May 1997.

4. "Criticality Safety Support Group (CSSG) White Paper," Memorandum from R. Dintaman to J. Tseng, January 20, 1999.

5. Defense Nuclear Facilities Safety Board Recommendation 94-1, *Improved Schedule for Remediation*, May 1994.

6. DOE Order 5480.24, *Nuclear Criticality Safety*.

7. DOE Order 420.1, *Facility Safety*.

8. ANSI/ANS-8.1-1998, *American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, American Nuclear Society, 1998.

9. Letter from Dr. Robin Staffin, Deputy Assistant Secretary for Research, Development and Testing (DP-10) to the Honorable John Conway, Chairman, Defense Nuclear Facilities Safety Board, February 2, 1998.

10. Subrecommendation 3 of the Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 97-2.

11. *SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluatio*n, April 1995. NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. I, II, and III, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, Oak Ridge, Tennessee.

12. Y. Karni and E. Greenspan, "The Swan Code for Minimum Critical Mass and Maximum k_{eff} Determination," p. 181, *Topical Meeting on Criticality Safety Challenges in the Next Decade*, September 8-11, 1997, American Nuclear Society.

13. United States Department of Energy Technical Program Plan for Development of Guidance for Defining Applicable Ranges of Bounding Curves and Data Relative to Nuclear Criticality Safety (NCS), Revision 4, September 28, 1998.

14. NRC JCN W6479, "Development and Applicability of Criticality Safety Software for Licensing Review;" Revision 0 dated 9/13/95, Revision 1 dated 4/26/96 and Revision 2 dated 05/27/97.

15. *Quarterly Status of the Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 97-2,* letter from R. Staffin to Chairman John T. Conway, August 1998.

16. *United States Department of Energy Department-wide Functional Area Qualification Standard: Nuclear Criticality Safety Qualification Standard Competencies*

17. *Guidance for Criticality Safety Engineer Training and Qualification*

Appendix A

Table A-1 contains a short summary of the collected experiments and includes an estimate of ranking and resource requirements. A more complete description of the experiments is contained in Appendix A of LA-UR-99-2083. The ranking estimates of low, medium, or high reflect the current priorities. The resource requirements are estimates of the experimental program funding necessary to complete the experiment or experimental program.

Table A-1. Summary of Proposed Experiments

Ident.	Description	Requestor	Category	Priority	Resources
98-1	Component Flooding Safety Benchmark Experiments	Steve Payne, DOE/AL Dave Heinrichs, LLNL	Extension of 501	High	Low
98-2	Single Unit / Array Benchmark Experiments	Dave Heinrichs, LLNL Adolf Garcia, DOE/ID	Extension of 501	High	Medium
98-3	Component Flooding Transient Behavior Experiment	Rick Paternoster, LANL Dave Heinrichs, LLNL	Extension of 504	Medium	High
98-4	Fissile Waste Matrix Benchmark Experiments	Blair Briggs, INEL	Restatement of 502, 609	High	Low
98-5	Pu Nitrate Solution with Boron & Gadolinium Poisons	Davoud Eghbali, WSRC	New 300 series	High	High
98-6	Experiments Representative of Fissile Accumulations in Yucca Mountain Tuft	Wesley Davis, Yucca Mtn	609 Ongoing	High	Low
98-7	Worths of Fission Products and Actinides in a Thermal Spectrum	Dale Lancaster, TRW Bill Lake, DOE/RW	Restatement Of 702, 502	Medium	Medium
98-8	Worths of Absorber, Structure and Reflector Materials In a Thermal MOX Spectrum	Dale Lancaster, TRW Bill Lake, DOE/RW	Restatement Of 702	Medium	Medium
98-9	Inelastic Scattering of Np237 Above Fission Threshold	Chuck Goulding, LANL	Restatement Of 601	High	Low - Medium
98-10	Central Ratio Measurements of Pu239 in Different Spectra	Bob Little, LANL Phil Young, LANL	Restatement Of 608	Medium	Low
98-11	Special Moderator Parameters	Calvin Hopper, ORNL	New base-theory	Low	Medium
98-12	Slowing Down Experiments in Water	Lester Petrie, ORNL	New base-theory	High	Low-Medium
98-13	Positive Bias in Pu / MOX Systems	Calvin Hopper, ORNL		Medium	Medium
98-14	Intermediate Enrichment Experiments	Calvin Hopper, ORNL Santiago Parra, NRC	Extension of 609	High	Medium
98-15	Critical Mass Experiments at Very Low Temperatures	Rene Sanchez, LANL Rick Paternoster, LANL	Extension of 107	Medium	Low

98-16	Bubble Formation and Reactivity Effects in Fissile Solutions	Prof. Sharif Hagar Univ. of New Mexico	207 Ongoing	Medium	Low
98-17	Radionuclide Extraction from Fissile Solutions	Prof. Gary Cooper Univ. of New Mexico	Extension of 504	Low	Low
98-18	Delayed Neutron Parameters in Higher Actinides	David Loaiza, LANL Ken Butterfield, LANL	605, 605a Ongoing	Medium	Low
98-19	Spectra and Yield Measurements of Delayed Neutrons	David Loaiza, LANL Ken Butterfield, LANL	605, 605a Ongoing	Medium	Low
98-20	Prompt Burst Behavior in LEU (5 – 20%) Solutions	Charlene Cappiello, LANL Ken Butterfield, LANL	Extension of 504	Medium	Low
98-21	Reactivity Temperature Coefficient in Dilute Pu Solutions	Rene Sanchez, LANL Rick Anderson, LANL	Extension of 504	High	High
98-22	Criticality Accident Alarm System (CAAS) Testing Program	Bill Casson, LANL	Restatement of 503	Medium	Low
98-23	Criticality Accident Dosimeter Intercomparison Studies	Bill Casson, LANL	Restatement of 503	Medium	Low
98-24	Neutron Dosimeter Calibration Studies	Bill Casson, LANL	Restatement of 503	Medium	Low
98-25	Environmental Neutron Dosimetry Studies	Bill Casson, LANL	Restatement of 503	Medium	Low
98-26	Transport of Low-Energy Neutrons in Various Materials	Bill Casson, LANL	New base-theory	High	Low
98-27	Source Jerk / Pulse Neutron Subcritical Measurements	David Loaiza, LANL Chuck Goulding, LANL	Restatement of 505	High	Low
98-28	Intermediate Neutron Energy Measurements	Bill Casson, LANL	609 Ongoing	High	Low

Table A-2 is a consensus ranking of the newly collected critical experiments needs combined with the current high-priority list. The members of the CSSG met and discussed the current experimental program and merged these new experiments into the existing priority list.

The 100, 200, 300, . . . etc. series numbers used in LA-12683 are included in Appendix A of document LA-UR-99-2083 to help relate those programs to the newly proposed experiments.

Table A-2. Revised Recommendations for Priority of Critical Experiments		
Priority	Identifier	Description
1	609. 98-28	Intermediate-energy reactivity-worth and dosimetry experiments for non-fissile matrix materials (ZEUS)
2	98-4, 98-6	Intermediate- and thermal-energy experiments with fissile material (^{233}U, ^{235}U, Pu) in specified waste matrices (e.g., Yucca Mountain tuft)
3	98-7	Measurement of worth of CERES fission-product samples for support of burnup credit (in SHEBA-II)
4	98-1, 98-2, 501	Single-unit and array experiments for pit storage and transportation (W-82, etc.), including experiments to simulate flooding/dissolution accidents
5	98-11, 501, 502a, 602	Experiments to determine effects of special moderators (e.g., beryllium, graphite, D_2O, high-density polyethylene) and absorbers (e.g., chlorine) on fissile materials in homogeneous and heterogeneous systems
6	98-8, 98-13	Lattice experiments with MOX fuel pins, including replacement measurements for various materials
7	98-22, 503	Criticality Accident Alarm System testing with SHEBA-II and Godiva
8	98-21	Verification of positive moderator temperature coefficient for dilute systems with nearly-pure ^{239}Pu
9	98-12	Extension of NIST neutron slowing-down experiments in water to larger spheres of water
10	98-27, 505	Source jerk / pulsed neutron measurements for subcritical systems

Priority 1: Intermediate-energy reactivity worth and dosimetry experiments using non-fissile matrix materials (ZEUS)

The objectives of this program are to provide validation for the integral cross sections at intermediate neutron energies as represented in common Monte Carlo and deterministic computer codes. The highest priority cross sections in this program are those for the three common fissile isotopes, ^{235}U, ^{239}Pu, and ^{233}U, in that order. Second priority is for those non-fissile matrix materials expected to be encountered. These include silicon, iron, aluminum, chlorine, and other materials. The Priority 2 program below extends measurements for these untested matrix materials (primarily waste matrix materials) to thermal neutron energies encountered when water or hydrogenous materials are present or are added to the system (e.g., in accident scenarios). Facilities management programs and clean-up or disposition programs which plan for the transportation, storage, and disposal of excess weapons materials and wastes all require this data, because such data either does not exist or is sparsely represented in the current validation database. Examples where the fissile materials cross section validations are needed include: casting isotopes of enriched uranium or weapons-grade plutonium into silicon or ceramic plates or logs (SRS); addition of iron to solutions or sludges containing these isotopes (Hanford waste tanks); burial of weapons grade material (Yucca Mountain); reactor use of weapons materials, including Actinides (MOX reactors, accelerator or reactor-based burners); drum storage and transportation (RFETS); removal from storage and disposal of ^{233}U (ORNL); disposal of machinery containing ^{235}U (ORNL); transportation and burial of spent reactor fuel, including civilian and military fuel (Yucca Mountain);

Priority 2: Intermediate- and thermal-energy in specified waste matrices

These objectives represent an extension of selected intermediate energy experiments for the untested matrix materials (primarily untested waste matrix materials) to thermal neutron energies. The beneficiaries of this data are primarily the facilities and programs dealing with waste and disposition activities. Such cross section test data is needed to support the ability to take credit for the presence of these isotopes in waste drums at the RFETS, for example.

Priority 3: Measurements of worth of CERES fission-product samples for support of burnup credit

These experiments are designed to test the cross-sections for the Actinides and fission-product isotopes contained in the CERES samples. Such cross-section test data is needed to support the ability to take credit for the presence of these isotopes in spent fuel. programs that store, transport, or dispose of such fuel (Yucca Mountain, reactor sites) will benefit from these measurements.

Priority 4: Single-unit and array experiments for pit storage and transportation, including experiments to simulate dissolution

These experiments are designed to validate safety analyses for accident scenarios for systems at issue (DoD, Pantex).

Priority 5: Experiments to determine effects of special moderators (e.g., beryllium, graphite, D_2O, high-density polyethylene) and absorbers (e.g., chlorine) on fissile materials in homogeneous and heterogeneous systems.

These experiments are an extension of the Priority 2 experiments to additional materials and special process situations such as low temperature. Materials such as beryllium at low temperatures are encountered in special process applications and in space.

Priority 6: Lattice experiments with MOX fuel pins, including replacement measurements for various materials

These experiments are designed to provide the validations for calculations of initial-design MOX reactors

Priority 7: Criticality accident alarm system testing with SHEBA-II and Godiva.

The devices are used to provide the radiation pulses to test CAAS systems under different accident conditions (e.g., fast pulse, slow cookers). All facilities, including NRC facilities, that have criticality alarms must validate the performance of these systems. Because the markets for these systems are so small, manufacturers often make changes in their products which then requires requalification of the system. The inability to qualify these systems would require some sort of exemption to ANSI/ANS-8.3 and to DOE Order O 420.1. Similar testing requirements must be met for dosimetry, and various other types of equipment and methodology. This experiment also includes measurements to understand the history of solution accidents. Such activities as measurements of power histories, evaluations of shutdown mechanisms, etc. are performed.

Priority 8: Verification of positive temperature coefficients for dilute systems with nearly pure ^{239}Pu

Some theoretical models predict a positive temperature coefficient for dilute Pu systems. If such an effect were demonstrated, it would mean that solution processing systems containing Pu at concentrations less than about 30 g/L could have more severe accident yields than previously thought. All facilities that have solution systems with Pu concentrations less than about 30 g/l would be affected by the results of these measurements.

Priority 9: Extension of NIST neutron slowing-down experiments in water to larger spheres of water

This is not a critical experiment, and would be performed at NIST.

Priority 10: Source jerk/pulsed neutron measurements for subcritical systems

These experiments are designed to produce subcritical benchmarks for typical process evaluations, most of which involve subcritical systems. There is currently no such validation database and these experiments would improve the validation status of almost all criticality safety evaluations.

Appendix B

The list below shows the contributions of several countries to the ICSBEP. All of these contributions have significant value and provide data that can no longer be obtained in the United States without major expense.

France:

Dilute plutonium solution data (applicable to operations and / or waste streams at RFETS, LANL, SRS, LLNL, INEEL and Hanford) as well as higher concentrations in single units and arrays. The first evaluation from France included plutonium-in-solution data with concentrations ranging from 13.2 to 105.0 grams per liter of solution. There are five experiments reported in this evaluation with plutonium concentrations below 20 g/L. These data fill a gap in the United States data which was considered important enough to warrant one of the top ten priority experiments (Experiment number 98-21 on the Priority Experiments List); however, there is still a need for data between 7.5 and 13 grams of plutonium per liter.

Assemblies that are highly sensitive to thick lead reflectors (applicable to the transportation and storage of spent nuclear fuels) -- Data on lead reflectors are very limited. These data are much more sensitive to the presence of lead than other currently available data.

Arrays of “damp” low enriched uranium dioxide units (applicable to waste systems and fresh fuel manufacturing activities) –Data for “damp” powders are also very limited. The uncertainties on the French data are much lower than the uncertainties on the small amount of data from other similar type experiments.

Low enriched and mixed uranium – plutonium fuel rod lattices (applicable to plutonium disposition activities)

Russian Federation:

Several experiments in which a significant amount of the neutrons causing fission fall into the intermediate energy range including k_∞ measurements on systems comprised of the components of stainless steel and zirconium (applicable to waste systems, large storage arrays, and code / cross section development activities – some of these experiments have pointed to deficiencies in US codes and cross section data.)

Numerous plutonium and uranium metal experiments with a wide variety of reflector materials

Numerous high, intermediate, and low enriched uranium solutions with and without various neutron absorbing materials. (applicable to waste systems and dissolution operations)

Water-moderated arrays of high and low enriched fuel rods and assemblies with various values of pitch and assembly separation – experiments with stainless steel dividers (applicable to spent fuel storage and transportation) – Included are data for uranium enrichments between 5% and 10% ^{235}U (funded by the NRC and the United States Enrichment Corporation).

Highly enriched uranium solution systems in various pipe intersections

In addition to existing criticality safety benchmark data, scientists from the Russian Federation have provided detailed spectral characteristics for all configurations in the international handbook.

Slovenia: Arrays of 20% enriched uranium TRIGA reactor fuel elements (applicable to transportation and storage of TRIGA reactor fuels at the INEEL) – Very little data exists for this type of fuel.

United Kingdom: K_∞ measurements for experiments with fast and intermediate energy spectra using plutonium in a graphite, stainless steel, sodium and natural uranium matrix (applicable to waste systems)

K_∞ measurements for experiments with intermediate energy spectra using plutonium in a graphite matrix and highly enriched uranium in a graphite matrix (applicable to waste systems)

Mixed plutonium – uranium systems (applicable to plutonium disposition activities)

Japan: 10% enriched uranium solutions with no reflector, water reflector, concrete reflector, and polyethylene reflectors.

Low enriched lattice experiments

Hungary: Over 200 critical configurations using VVER fuels – (Applicable to US efforts to assist with safety analysis of these types of fuels)

Korea: Evaluation of two series of US mixed oxide experiments

Yugoslavia Highly enriched, low enriched, and natural uranium heavy-water-moderated lattices

Over 150 scientists from around the world have combined their efforts to document the work of the ICSBEP as the "International Handbook of Evaluated Criticality Safety Benchmark Experiments". The handbook is currently being used in 35 different countries. The following table summarizes where handbook has been distributed.

Table B-1. Distribution of the "International Handbook of Evaluated Criticality Safety Benchmark Experiments"

Affiliation/Company	Number
Argonne National Laboratory	13
Babcock & Wilcox	2
Defense Threat Reduction Agency	1
Department of Energy	12
Foreign Countries	103
Hanford Site	10
Idaho National Engineering & Environmental Laboratory	12
Los Alamos National Laboratory	21
Lawrence Livermore National Laboratory	28
Military (Army, Air Force, Navy)	8
United States Nuclear Regulatory Commission	8
Oak Ridge National Laboratory	18
Oak Ridge Y-12 Plant	4
Oak Ridge K-25 Plant	2
Other / Consultants[1]	62
PANTEX	1
Pacific Northwest National Laboratory	1
Rocky Flats Environmental Technology Site	15
Sandia National Laboratory	4
Universities	31

Utilities	17
Westinghouse Safety Management Solution at Savannah River Site	19
Yucca Mountain Project	2
Consultants and consulting firms that almost exclusively support one particular DOE laboratory are including in the distributions to that laboratory	